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TMOS Power FET Design Ideas



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TMOS Power FET Design Ideas


The circuits in this brochure represent the top 50 circuits selected from hundreds of circuits that were entered in the Motorola TMOS design contest. The entries were judged for originality and creativity as well as for opening new avenues of efficiency, simplicity, economy, uniqueness, functionality and performance. The entries were judged by a panel of engineers at Motorola and the winning entries were selected by a staff at Electronic Design News.

These circuits are published to give you an idea of some of the applications that power MOSFETs can serve and to stimulate your thoughts to design with the state-of-the-art power control devices — Motorola TMOS power FETs.

Congratulations to those that won and thanks to all those that participated in the contest.

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TABLE OF CONTENTS

Page

Audio

50 W Audio Power Amplifier	1
Jack D. Grimes, San Jose, CA	
Class-D Power Amplifier	2
Aldo Cugini, Stamford, CT	

Automotive

Automotive Air Conditioner "Smart" Clutch	3
Stan Sitts, Madison, WI	
Intermittent Windshield Wiper With Dynamic Braking	4
Vincent Salerno, Hicksville, NY	

Battery Systems

NiCad Battery Protection Circuit	5
L. A. Turner, Atlanta, GA	
Low-Battery Protection Circuit	6
Djordje Boskov, Lombard, IL	
Dynamic, Constant Current Load for Fuel Cell/Battery Testing	7
Christopher Ziolkowski, Chicago, IL	
Battery Charger Operates On Single Solar Cell	8
Philip Smith, Sandston, VA	

Circuit Techniques

Current-Driven Synchronous Rectifier	9
William R. Archer, Fort Wayne, IN Grand Prize Winner	
High Performance Isolated Gate Drive	11
Neil Rasmussen, Burlington, MA Third Prize Winner	
Constant Current, High Compliance Source/Sink	12
Richard Walter, Parsippany, NJ	
High Voltage Switching Circuit	13
Mike Willingham, Mansfield, TX	
Low Forward Drop Rectifier Circuit	14
Bruce Rosenthal, Sunnyvale, CA	
300 V Pulse Generator	15
Daniel Gray, Calgary, Alberta, Canada	
Fast Overvoltage Protection With No Latchup	16
Charles E. Browder, Ft. Lauderdale, FL	

Circuit Techniques

High Speed Electronic Circuit Breaker..... 17
D. Newton, Culver City, CA

Line Driver Provides Full Rail Excursions 18
Stan Harrison, Parker, CO

Illumination

Light-Controlled Lamp Switch 19
Dennis Baldrige, Bourbonnais, IL

Machine Vision Illumination Stabilizer 20
Scott Juds, Everett, WA

DC Lamp Dimmer..... 21
Mark Molnar, Bellville, OH

Lamp Life Extender 22
B. E. Anderson, Rockville, MD

Miscellaneous

Safety Shutdown Monitor 23
Buddy J. Cook, Tigard, OR

Proportional Temperature Controller 24
Douglas Jewett, Ann Arbor, MI **Third Prize Winner**

120 kHz, 500 W Induction Heater 25
Ron Doctors, Santa Barbara, CA

TMOS Sonar Transducer/Switch..... 26
Russell Thynnes, Seattle, WA

Magnet Current Regulator..... 27
Steven Young, Menlo Park, CA

200 Vdc Piezoelectric Gas Valve Switch 28
Mark Strauch, Livermore, CA

Motor Speed Control

PWM Speed Control and Energy-Recovering Brake..... 29
L. K. Palmer, Las Vegas, NV **Third Prize Winner**

Back EMF PM Motor Speed Control 31
Jim Alleman, Houston, TX

PWM Motor Speed Control..... 32
Robert Ritzsche, Chaska, MN

Power Sources

High Efficiency, Off-Line Switching Power Supply 33
Marek Gajenski, Woodland Hills, CA **Third Prize Winner**

Complementary Output Variable Frequency Inverter 35
Steve Bennett, Two Rivers, WI

Self Oscillating, Flyback Switching Converter..... 36
Douglas Glenn, Lewisburg, TN

Radiation-Hardened, 125 A Linear Regulator..... 37
Tom R. Seaton, Portland, OR

Low Cost, Very Low Dropout Linear Regulator 38
Aubrey Elms, Marlboro, MA

1.5 W Offline Converter 39
Woody Skelton, Boulder, CO

High Voltage Bucking Regulator 40
Jim Hagerman, Maynard, MA

High Efficiency Flyback Voltage Converter..... 41
James Marshall, Dallas, TX

HV Regulator With Foldback Current Limiting 42
Larry Sears, Cleveland, OH

Uninterruptable Power Supply For Personal Computers..... 43
Bill Williams, Columbus, OH

RF Communications

High Efficiency, 80-Meter Amateur Radio Transmitter..... 44
Robert G. Culter, Beaverton, OR **Second Prize Winner**

Double Sideband, Suppressed Carrier R.F. Modulator 45
Larry Lockwood, McMinnville, OR **Third Prize Winner**

Low Distortion, High Power AM Transmitter Modulator..... 46
Fred Studenberg, Melbourne, FL

Balanced TMOS VCO..... 47
John Jones, Dayton, OH

RF Power Switch 48
Robert Rouquette, Harahan, LA

Servo Amplifiers

μ P-Controlled Servo Amplifier With TMOS-Darlington Output	49
Ned Dammeyer, New Bremen, OH	
400-Hz Servo Amplifier	51
Larry Ducas, Industry, CA	
Maximum Efficiency H Bridge Power Amplifier	52
Lealon R. McKenzie, Tulsa, OK	
PWM Servo Amplifier	53
Darrel Russon, Seattle, WA	
DC Servo Drive Employs Bipolar Control Input	54
Davide Andrea, Boulder, CO	
Servo Motor Drive Amplifier	55
S. M. Killough, Oak Ridge, TN	

TMOS Power MOSFET Selector Guides

Plastic TMOS Power FETs	
TO-220AB (Case 221A-02) — Table 1	57
TO-218AC (Case 340-01) — Table 2	60
TO-225AA (Case 77-04) — Table 3	61
Metal TMOS Power FETs	
TO-204AA (Formerly TO-3; Case 1-04,-05) — Table 4	62
Energy Management Series — Table 5	66
Gain Enhanced GEMFETs — Table 6	66
P-Channel — Table 7	67
Military — Table 8	67
Small-Signal (TO-116, TO-205AD, TO-206AA, TO-226AA, TO-226AE) — Table 9	68
Small-Signal (TO-205AF) — Table 10	69
Small-Signal — 4-Pin DIP — Table 11	69
Product Matrix — Table 12	70

Audio

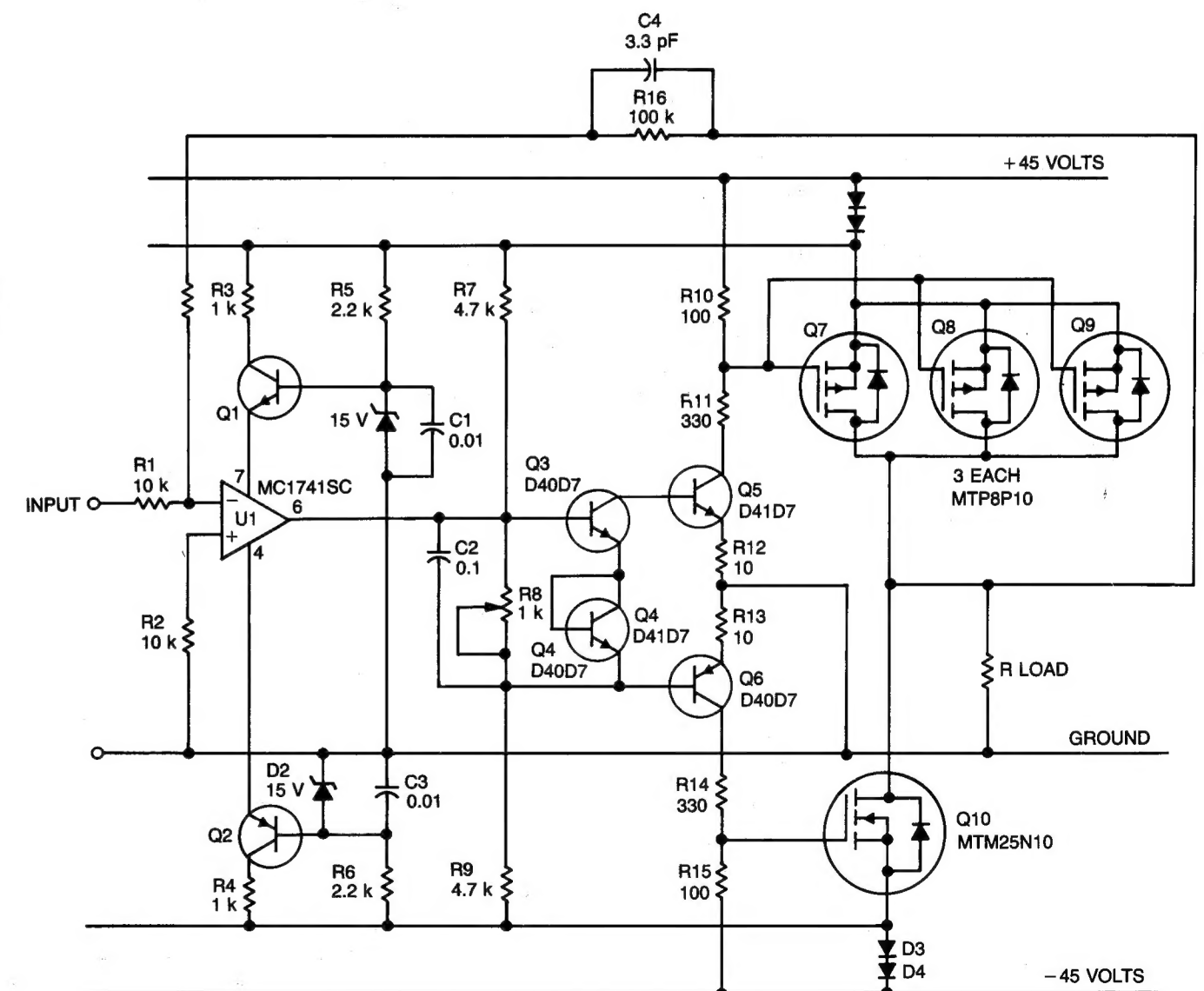
50 W Audio Power Amplifier

Jack D. Grimes, San Jose, CA

This audio amplifier design approach employs TMOS Power FETs operating in a complementary common source configuration. They are biased to cutoff and then turn ON very quickly when a signal is applied. The advantage of this approach is that the output stage is very stable from a thermal point of view.

Turn-on switching speed must be very fast in order to obtain very low harmonic and phase distortion. Bipolar output transistors cannot provide the desired results, but TMOS devices are much faster with better SOAs and can produce the desired results.

U1 is a high slew rate operational amplifier that drives Q3, Q4, Q5 and Q6 (operating Class AB) that provide level translation for the output stage consisting of Q7, Q8, Q9 and Q10. The positive temperature coefficient of the TMOS devices enables parallel operation of Q7, Q8 and Q9 and provides a higher power "complementary" device for Q10. These TMOS Power FETs must be driven from a low source impedance, $<100\Omega$, in order to actually obtain high turn-on speeds.



Class-D Power Amplifier
Aldo Cugini, Stamford, CT

Requirements for a Class "D" power amplifier are much tighter than those for more conventional amplifiers. Output devices must be able to pass a substantial amount of current and have an extremely low ON resistance.

In this circuit, a 2-MHz clock is divided by eight in U1, providing a stable 250 kHz carrier. Q1 and Q2 buffer the clock and provide a low impedance drive for operational amplifier U4, which is a high gain amplifier and integrator. U4 accepts audio inputs and converts the 250 kHz square wave into a triangular wave. The summed audio and triangular wave signal is applied to the input of comparator U7 where it is compared with a dc reference to produce a pulse width modulated signal at the output of U7.

The differential outputs from U7 drive high speed optoisolators U9 and U10, which isolate the input stage from the high voltage output stage. The two isolators drive upper and lower circuits that are identical except for their respective power sources. The lower section derives its power from regulator U12, whose input is 20 V above the -50 V supply (i.e., -30 V). The upper section gets its power from a high frequency power inverter consisting of U11, RS flip-flop U2, driver U3, pulse transformers T1 and T2, and diode D4.

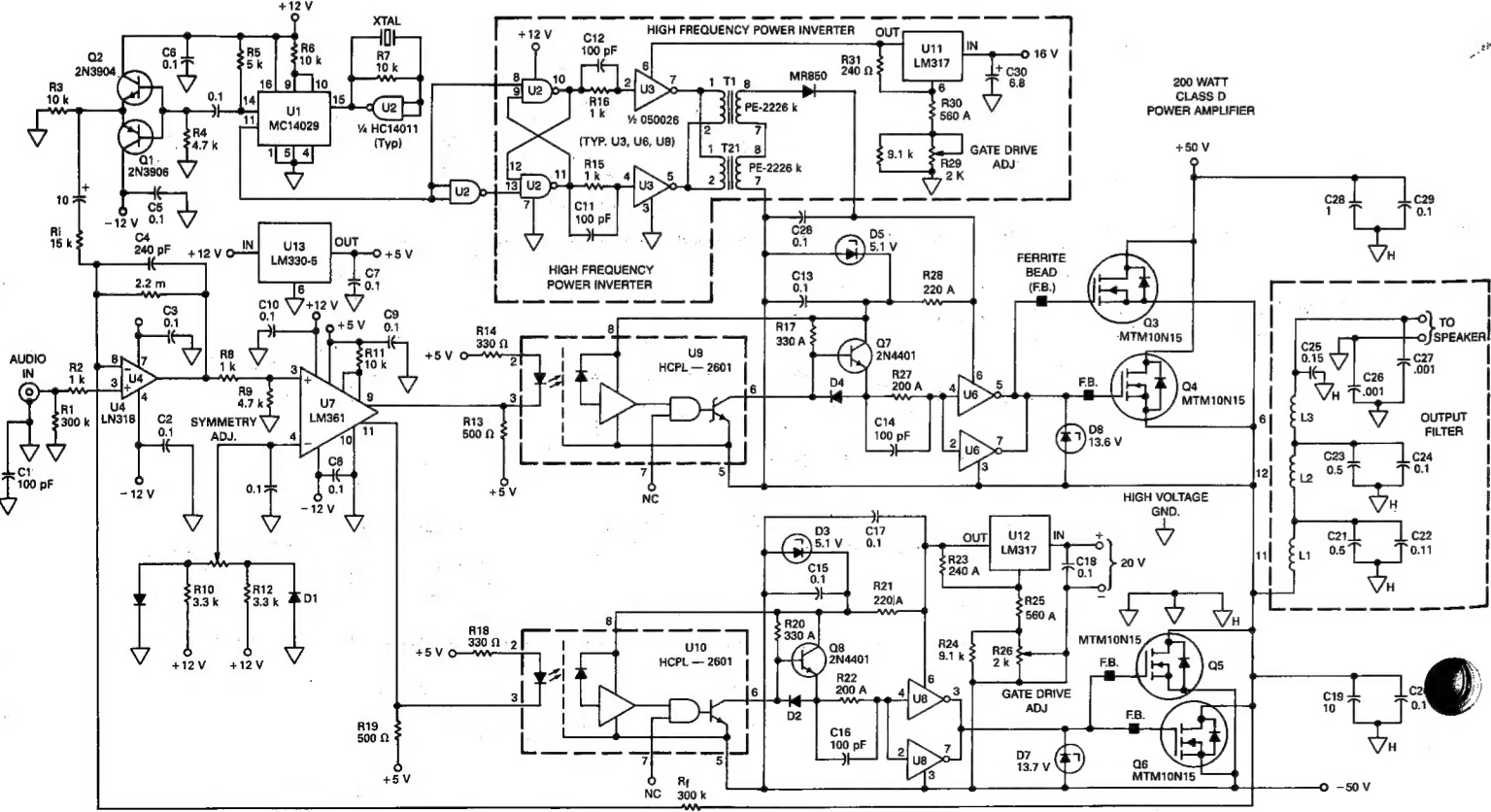
Pin 6 of U9 is connected to an active pull-up circuit and applied to clock driver U6, which is a high speed, high current source and sink. Outputs from U6 drive Q3 and Q4 TMOS devices, whose gates are protected by zener D8.

Q3 and Q4 require V_{GS} to be referenced to the output line, so a bootstrap supply is needed. This is the reason for the high frequency power inverter circuit.

Pin 6 of U10 also has an active pull-up circuit and its signal is applied to clock driver U8. Outputs from U8 drive Q5 and Q6 TMOS devices, whose gates are protected by zener D7.

The output devices switch between the +50 V and -50 V rails in a complementary fashion, driving the output filter that is a sixth-order Butterworth low pass type, which demodulates the audio and attenuates the carrier and high frequency components. Feedback is provided R_f ; amplifier gain is R_f/R_i .

SPECIFICATIONS: 200 W continuous power into a 4 Ω load; 20 to 20 kHz frequency response +0.5, -1.0 dB @ 200 W; THD, IMD <0.5% @ 200 W; 1.5 V RMS input for rated output; 69 dB S/N ratio, "A" weighting; 6.6 V/ μ sec slew rate.



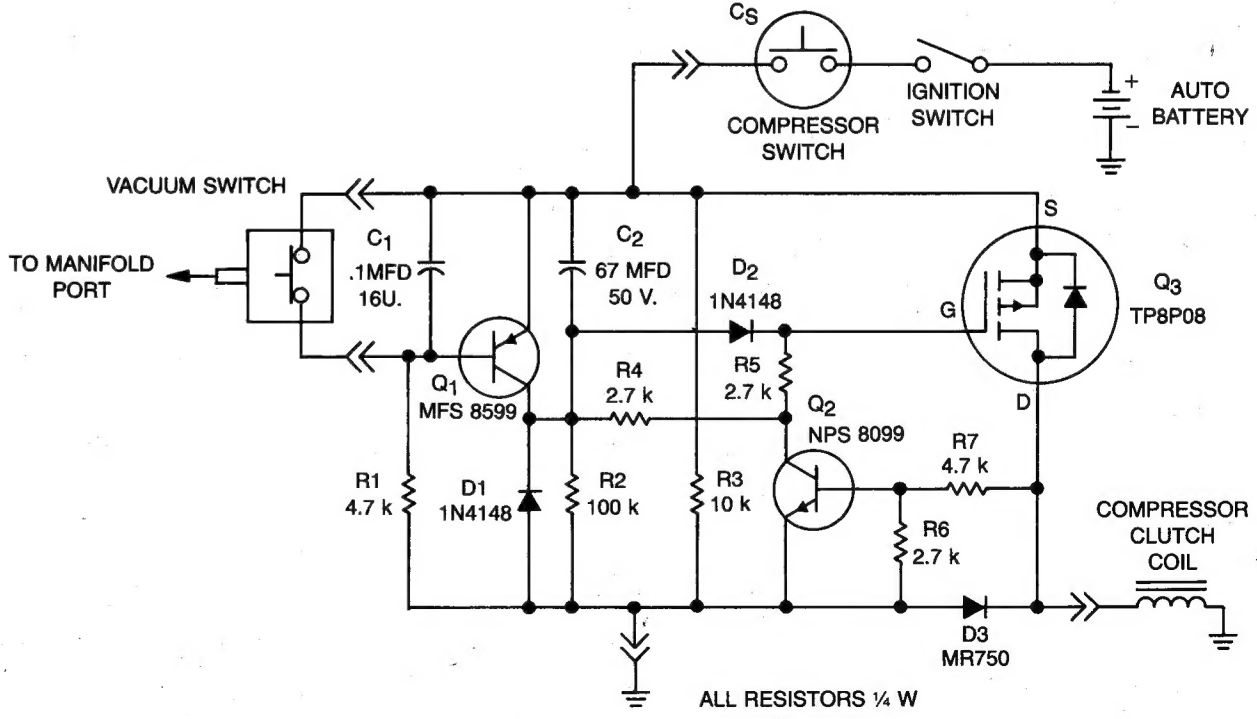
Automotive Air Conditioner "Smart" Clutch
Stan Sitts, Madison, WI

Unnecessary auto engine loading, such as an air conditioner, can become a safety factor because it reduces acceleration and slows response time. For example, an automobile air conditioner requires 3 to 5 HP from the engine during normal operation.

The "Smart Clutch" solves the air conditioner loading problem by disabling the air conditioner compressor when additional engine power is required. It does so by monitoring the engine vacuum at the intake manifold. If the vacuum drops to 40% of its normal level, the compressor clutch is disabled, removing the air conditioner load from the engine. After the engine returns to a normal vacuum level, there is 6 sec delay, the compressor clutch is enabled and the air conditioner is activated. This allows 6 sec of extra power (about 500 ft at 60 MPH), which increases the safety margin when passing another vehicle. Loss of cooling is minimal because the air conditioner fan is not interrupted. When the engine is accelerated, manifold vacuum drops and vacuum switch, VS, opens at 40% of the normal manifold pressure. This causes Q1 to turn ON, discharging C2 and turning OFF Q3 via diode D2. When Q3 turns OFF, so does Q2. When the engine reaches its normal operating vacuum, VS closes and Q1 turns OFF, allowing C2 to charge for six seconds until Q3 turns ON again.

Another situation to be considered occurs when the engine is started with the air conditioner ON, which puts an additional load on the starter and battery. For this situation, the compressor switch, CS, and the ignition switch are closed, applying 12 V to the R2-C2 time constant. The C2 charging voltage appears at the gate of the MTP8P08 (Q3) via R4 and R5. Q3 starts to turn ON after six seconds, when its threshold voltage is exceeded. When Q3's drain voltage reaches 1.5 V, it turns ON Q2, which switches Q3 ON faster and applies power to the compressor clutch coil. During this time, the vacuum switch is closed because manifold pressure is high; thus, Q1 has no effect. During normal operation, as compressor switch CS cycles, the 6 sec delay is in effect and diode D1 allows rapid discharging of C2 via R3 and D1. Capacitor C1 helps keep vacuum switch VS contacts clean and reduces RFI susceptibility. Diode D3 is optional; it is a coil snubber for EMI reduction.

Vacuum switch requirements for 8-cylinder engine: mechanical contacts open at 4-in. vacuum and close at 6-in. vacuum. The sensor is similar to Fairchild PSF100A pressure sensor. Motorola MPX100 or MPX200 Series transducers with a ported package and an amplifier could replace VS and Q1.



Intermittent Windshield Wiper With Dynamic Braking

Vincent Salerno, Hicksville, NY

This circuit provides a delayed windshield wiper and dynamic braking of wiper blades when they reach the rest position. Dynamic braking prevents the blades from overshooting, which might cause them to stop at a point where they might interfere with the drivers vision.

With the original wiper switch OFF, switch S1A turns ON the delay circuit and S1B disconnects the original automotive wiring. When S1 is turned OFF, the original wiring controls the system and the delay circuit is bypassed.

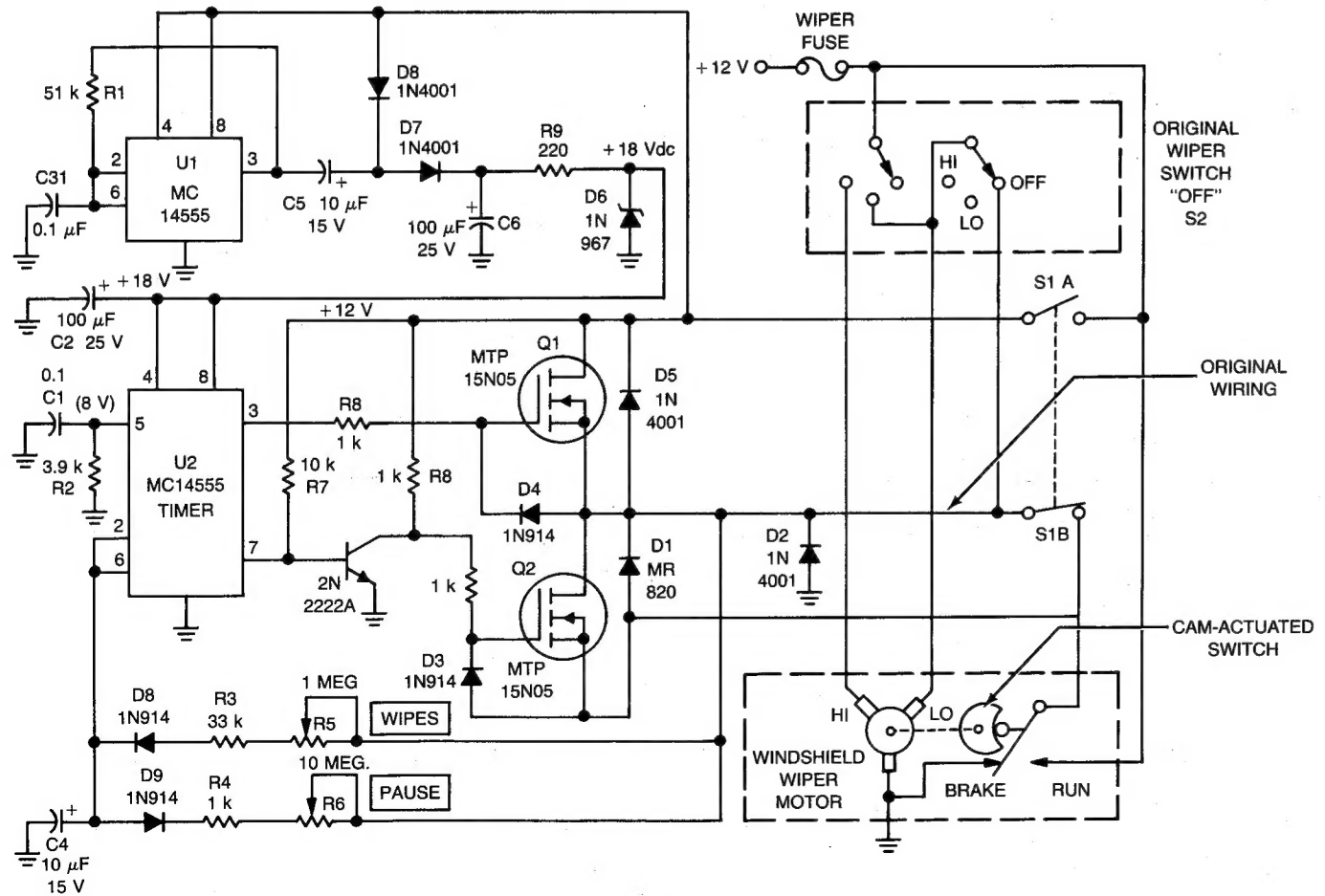
Turning S1 ON applies the +12 V battery to U1, which is a voltage doubler that produces +18 V. This higher voltage supply is necessary to insure reliable turn ON of Q1 by multivibrator U2. This arrangement provides about +18 V to the gate of Q1, whose source is +12 V minus the V_{DS} drop of Q1.

The voltage from the common point of the Q1-Q2 "to-tem pole" is applied to the wiper motor (via S1A and the original wiper switch). This moves the cam-actuated switch from the BRAKE (ground) position to the RUN

(+12 V) position and back to the BRAKE position when the wiper blades return to the rest position. When C1 reaches +8 V, U2 fires, turning Q1 OFF and Q2 ON if the cam switch has reached the BRAKE position. This places a short circuit across the motor terminals, dynamically braking it. If the cam switch is still in the RUN position, the motor continues to be energized through D1, and Q2 is turned OFF. When the cam switch reaches the BRAKE position, Q2 turns ON because the gate is +12 V and the source is at ground. Again, the motor is shorted and dynamically braked.

Q1 remains ON for a time determined by the WIPES potentiometer that controls the number of wipes before pausing. The interval between wipes is controlled by the PAUSE control. When C1 drops below +4 V, U2 fires, turning Q1 ON and restarting the cycle.

Diodes around Q1 and Q2 provide protection against transients generated by the motor. D2 is a "free-wheeling" diode that prevents a large back EMF from being generated by the motor when the power is suddenly removed.



NiCad Battery Protection Circuit

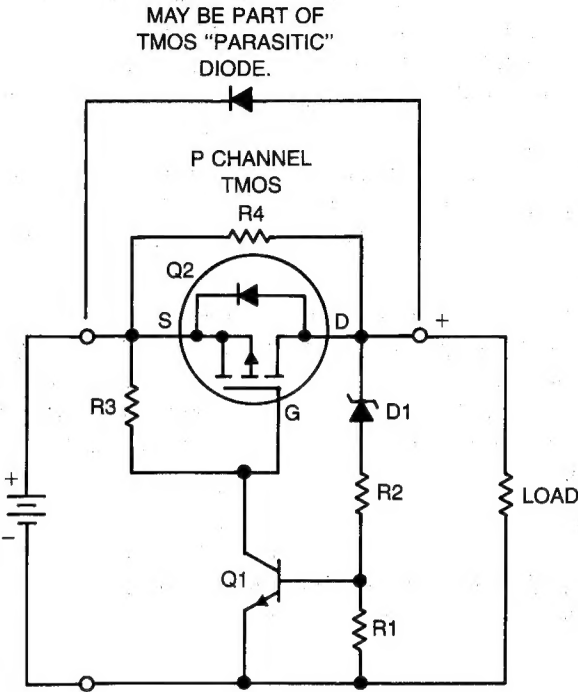
L. A. Turner, Atlanta, GA

If a NiCad battery is discharged to a point at which the lowest capacity cell becomes fully discharged and reverses polarity, that cell will usually short internally and become unusable. To prevent this type of damage, this circuit detects a drop of 1.25 V (one cell voltage) and turns the load OFF before cell reversal can occur.

This circuit takes advantage of the high input impedance and low series resistance of TMOS devices to keep the circuit power consumption so low that battery shelf life, or self-discharge time is not affected.

A low current zener or other voltage sensor (D1) and resistors R1 and R2 establish a reference level for transistor Q1. These resistors bias the zener to a few microamperes above its "knee". Therefore, if battery voltage falls more than 1.25 V, Q1 turns OFF, turning OFF Q2, and disconnecting the load. After the load is disconnected, if the battery returns to nominal voltage, the high value of resistor shunting Q2 provides enough output voltage to "reset" the voltage sensor and turn Q2 back ON. If desirable, a shunt diode, D2, or the parasitic diode of the TMOS device (if suitable) allows the battery to be charged from the load terminals.

The protection circuit presents a shunt current of only 10 mA at nominal battery voltage, which is low relative to the internal leakage of the batteries.



Battery Systems

Low-Battery Protection Circuit

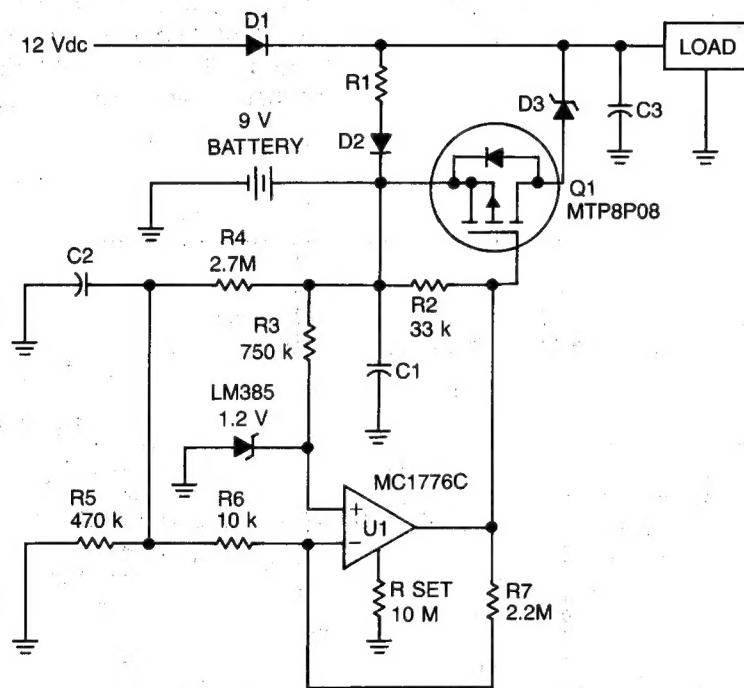
Djordje Boskov, Lombard, IL

A battery backup is commonly required when the operation of electronic circuits has to be extended during a power loss. The size of the backup battery is determined by the current consumption and the duration of the backup period. For an extended power loss there is a danger of over-discharging the battery, which can result in permanent battery damage.

To prevent battery damage, a low voltage detector and switch should be included in the design of the battery backup circuit. The detector circuit should consume extremely low current. The switch should exhibit a low voltage drop and be easy to control.

The circuit shown here is for use with a 9 V battery and very nearly satisfies the above criteria. It incorporates an MTP8P08 P-channel TMOS device (Q1) as a switch, an MC1776 (U1) programmable operational amplifier and a micropower voltage reference, LM385 (D4). U1 operates as a comparator with the advantage of a very low ISET.

In operation, R1 and D2 provide a trickle charge for the battery. Chosen for its low forward voltage drop, a Schottky diode (D3) prevents forward polarization of the diode incorporated in Q1. When the battery voltage is above approximately 8 V, the output of U1 is low and Q1 is turned ON. If the battery voltage falls below 8 V, the output of U1 goes high and turns OFF Q1.



Battery Systems

Dynamic, Constant Current Load for Fuel Cell/Battery Testing

Christopher Ziolkowski, Chicago, IL

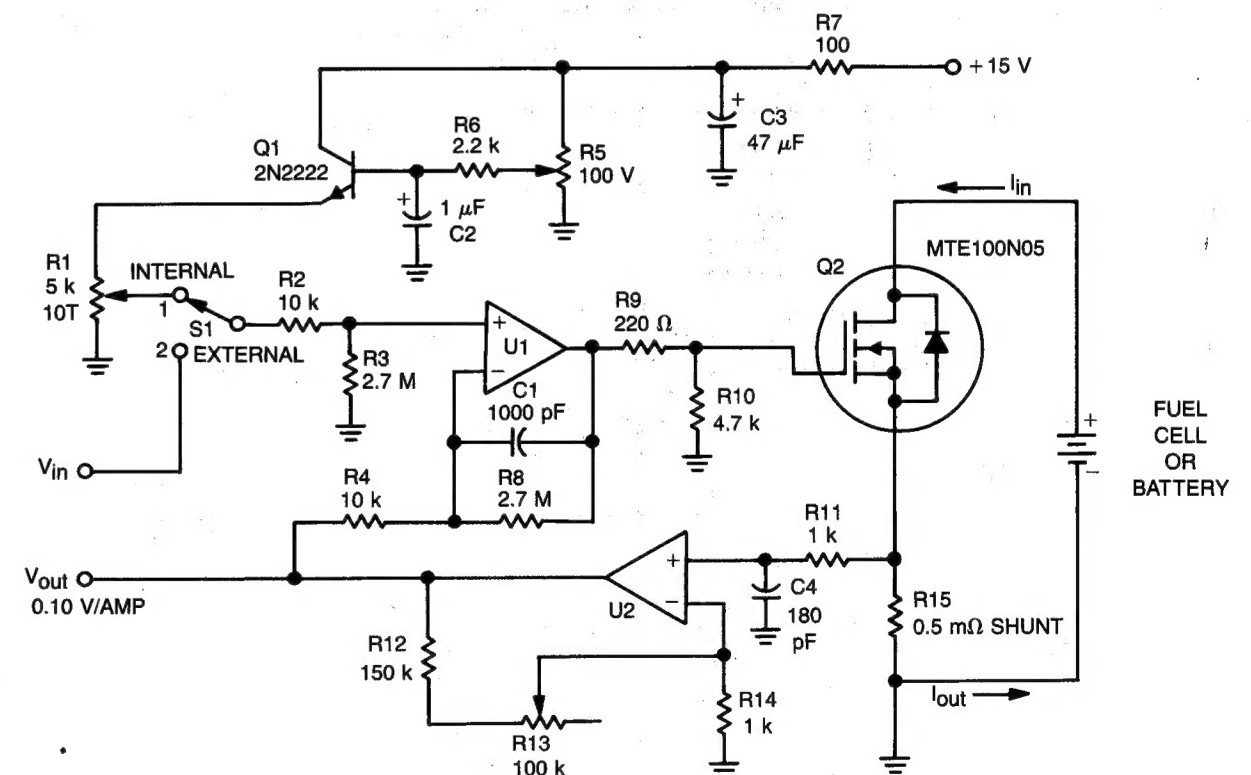
This circuit was designed for use in testing fuel cells, but it could also be used for testing batteries under a constant current load. It provides a dynamic, constant current load, eliminating the need to manually adjust the load to maintain a constant load.

The dynamic load can also be used for two other tests. First, the electrode capacitance can be measured under load by imposing an ac signal on top of the dc controlling the base load. Second, recovery time can be tested by loading the cell to a given current, then disconnecting the load, which allows the cell voltage to recover to its open-circuit value in a characteristic time. (The TMOS device can "disconnect" the load far faster than any mechanical switch). The dynamic load truly is dynamic because it provides a testing capability that is not possible with a passive load.

For fuel cell applications, the load must be able to absorb 20-40 A, and since a single cell develops only 0.5 to 1.0 V, bipolar power devices (such as a Darlington) are impractical. Therefore, this dynamic load was designed with a TMOS Power FET (Q2).

With switch S1 in position 1, emitter follower Q1 and R1 establish the current level for the load. In position 2, an external voltage can be applied to control the current level.

Operational amplifier U1 drives TMOS device Q1, which sets the load current seen by the fuel cell or battery. The voltage drop across R15, which is related to the load current, is then applied to U2, whose output fed back to U1. Thus, if the voltage across R15 should tend to change, feedback to the minus input of U1 causes that voltage (and the load current) to remain constant. Adjustment of R13 controls the volts/amp of feedback. The V_{OUT} point is used to monitor the system.



Battery Systems

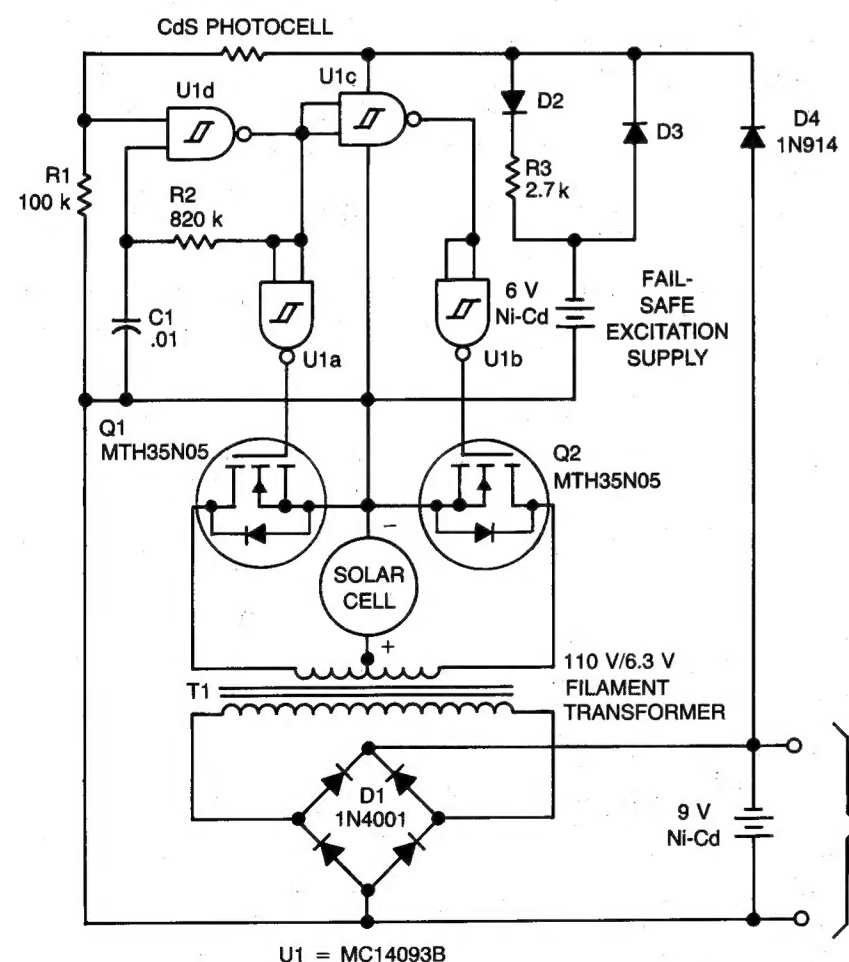
Battery Charger Operates On Single Solar Cell

Philip Smith, Sandston, VA

Operating from a single solar cell, the circuit shown charges a 9-V battery at about 30 mA per input ampere at 0.4 V. It can operate in a parallel battery configuration, that is, with a number of the same voltage cells in parallel. With the parallel cell system, changes in power requirements can be accommodated by merely adding or subtracting cells, whereas a series system must be completely redesigned to change power levels.

U1, a quad Schmitt trigger, operates as an astable multivibrator to drive push-pull TMOS devices Q1 and Q2. Power for U1 is derived from the 9-V battery via D4; power for Q1 and Q2 is supplied by the solar cell. The multivibrator frequency, determined by R2-C1, is set to 180 Hz for maximum efficiency from a 6.3 V filament transformer, T1. The secondary of the transformer is applied to a full wave bridge rectifier, D1, which is connected to the batteries being charged. The small NiCad battery is a fail-safe excitation supply to allow the system to recover if the 9-V battery becomes fully discharged.

A CdS photocell shuts off the oscillator in darkness to preserve the fail-safe battery during shipping and storage, or prolonged darkness.



Circuit Techniques

Current-Driven Synchronous Rectifier

William R. Archer, Fort Wayne, IN Grand Prize Winner

A simple, two-terminal synchronous rectifier can be implemented with a TMOS Power FET, as shown in Figure 1. This configuration takes advantage of the Power FET's equivalent circuit, which can be considered as a conventional diode in parallel with a controllable resistor. When turned ON, the voltage across the Power FET is essentially a linear function of the current through it. This is true for both the conventional (drain-to-source) and reverse (source-to-drain) polarity. The reverse polarity is the normal forward conducting polarity of the synchronous rectifier.

A synchronous rectifier using a Power FET with a low $R_{DS(ON)}$ at the required current can provide better results than a conventional or Schottky rectifier. The MTM60N05 selected for this circuit has an $R_{DS(ON)}$ of less than 30 milliohms at 10 A.

Key to operation is toroidal current transformer, CT1, whose core is slipped over the wire connected to the source. CT1 has two secondary windings, one with three turns and the other with 25 turns. Therefore, a source current, I_S , causes $.04I_S$ in the 25-turn secondary, which flows through diode D1 into the gate of Power FET Q1. This charges the input capacitance of Q1, turning it ON. Charging is terminated by saturation of CT1, which causes all windings to appear shorted. Therefore, transistor Q2 is solidly held OFF, D1 is reverse-biased, and the input capacitance of Q1 holds its charge. In this state, Q1 is fully enhanced and the resultant $R_{DS(ON)}$ effectively forces all the forward diode current through Q1, bypassing the internal parasitic diode. In this situation, Q1 acts as a high efficiency diode.

The saturated core of CT1 has a magnetizing current stored in it of a polarity that if unopposed would cause all the windings to reverse their original polarity. That is, the three-turn secondary would make the base of Q2 positive, turning it ON. This would rapidly discharge the input capacitance of Q1 and turn it OFF, allowing the synchronous rectifier to block current flow from "C" to "A." The magnetizing current of CT1 is overpowered by the forward current flowing in the one-turn primary. However, when the external load circuit attempts to reverse current flow, this magnetizing current becomes dominant, turning Q2 ON and Q1 OFF.

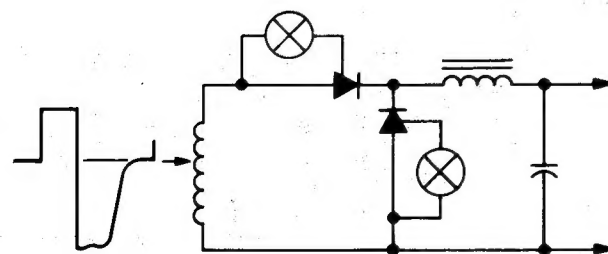
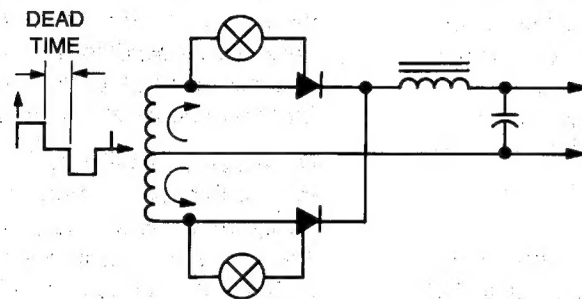
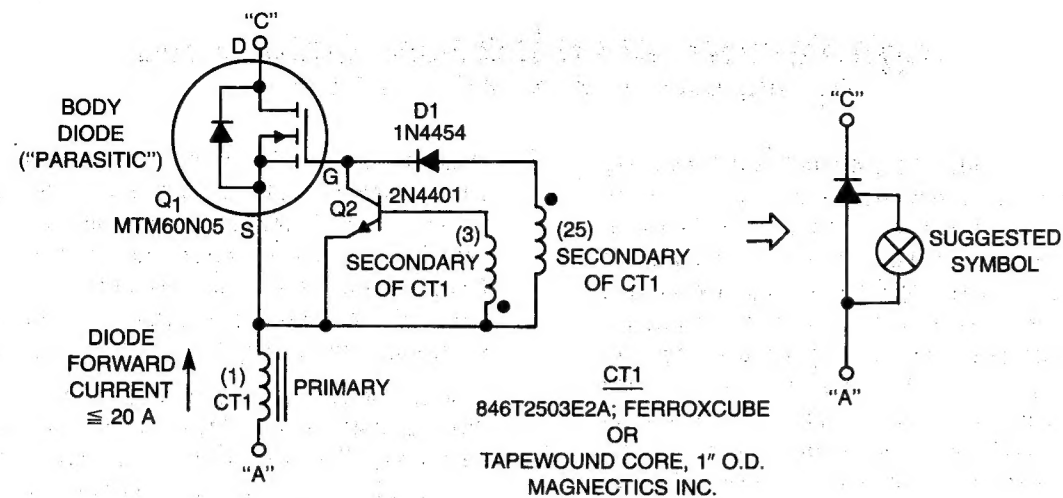
When the synchronous rectifier is blocking, CT1 is automatically reset. Also, Q2 base-emitter clamps the reset and guarantees that Q2 is conducting, which provides a low impedance from gate-to-source of Q1 during its critical high dv/dt recovery interval. This prevents false turn-ON even in "square wave" systems.

Turn-OFF time of the synchronous rectifier is controlled by Q1 and not the parasitic diode because the diode does not carry any current because the Power FET has effectively shorted it.

Proper turn-ON and turn-OFF of Q1 is accomplished by the actual load current without any external control or timing signals. Thus, the synchronous rectifier appears as a true two-terminal rectifier.

Figure 2 shows a full wave synchronous rectifier. Note that when this transformer is driven from a classic PWM converter with "dead time", the synchronous rectifier works perfectly. The inductor current divides equally between the two halves of the transformer and the two diodes, then it commutates when the next PWM stroke occurs. Note that during the "dead time" the secondary of the power transformer is essentially short circuited, thus eliminating the possibility of using auxiliary windings to drive a synchronous rectifier.

A forward converter for virtually any high frequency application is shown in Figure 3. There is no need for a special secondary winding to control the Power FETs and this would become especially difficult here anyway because of the lack of a common terminal. At very low current levels the Power FET may not be fully enhanced due to the lack of suitable drive, but the only consequence is that under this condition the load current flows in the parasitic body diode. At low current levels the benefit of the reduced Power FET voltage drop is not as important.



Circuit Techniques

High Performance Isolated Gate Drive

Neil Rasmussen, Burlington, MA *Third Prize Winner*

Isolated Power FET gate drive circuits are necessary in many applications. One of the more widely used isolation techniques involves the opto-isolator, however these devices have a limited immunity to common mode swings (false triggering when the common mode dv/dt rating is exceeded). The best isolators have a common mode transient limit of only 1000 V/nsec. An off-line power supply or motor drive using a full of half bridge configuration can easily experience swings of 320 V in under 100 nsec with respect to the control circuits. This exceeds the limit of available isolators by a factor of three.

Another problem with opto-isolators is speed. Systems using opto-isolators require a power supply floating with each driven Power FET, and even the fastest opto-isolators are relatively slow compared to Power FETs.

Transformer isolation systems provide high speed, but suffer from severe problems in some applications. The maximum ON time is limited by core saturation and the minimum On time is limited by the magnetizing current that is needed to help turn OFF the Power FET. In addition, transformer duty cycle is usually limited to to 50%, maximum, for a simple system or 80% with a complex scheme. This fundamental limit occurs because the flux in the core must be reset by balancing volt-seconds after each Power FET ON period.

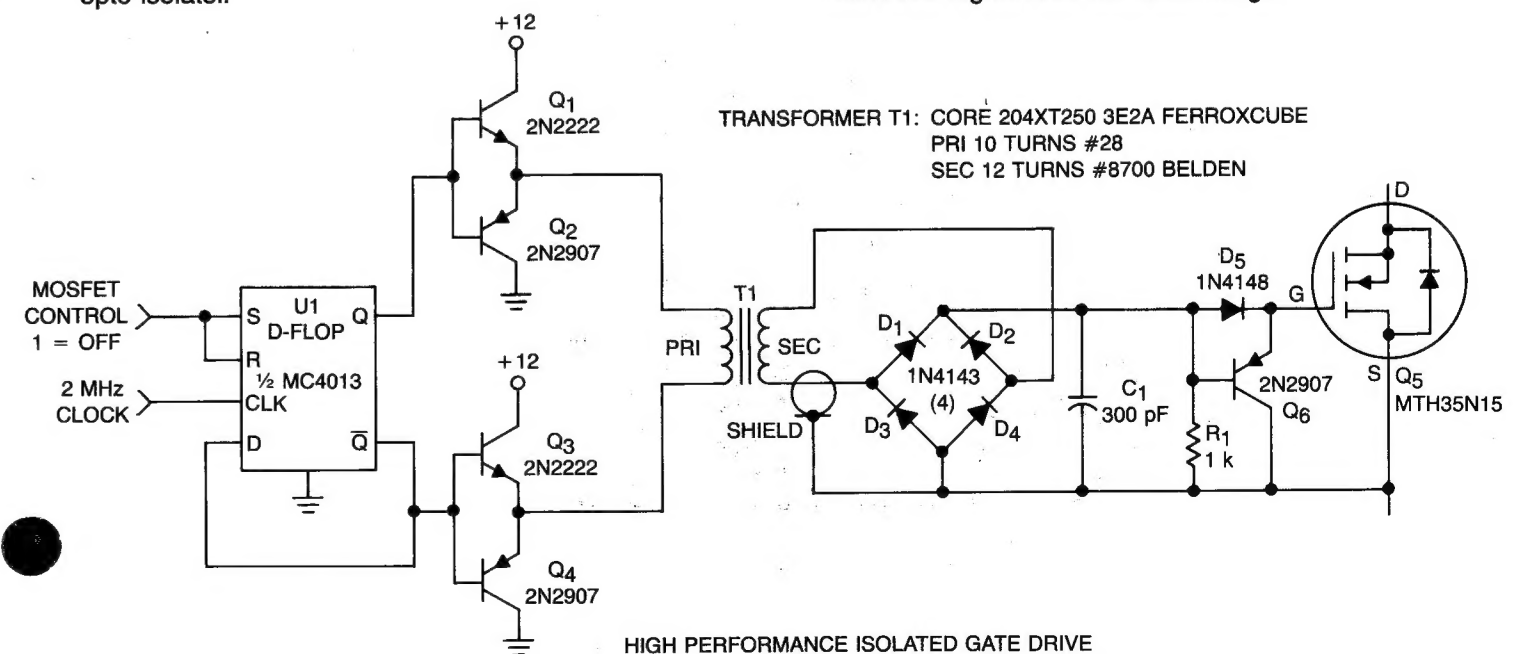
The "gated carrier" circuit shown here has the speed and common mode immunity advantages of the transformer isolation system combined with the unlimited flexibility of ON times and duty cycle offered by the opto-isolator.

In operation, a "D" flip-flop (U1) produces a 1 MHz carrier, which is gated by a control signal applied to the flip-flop. The Power FET ON voltage is supplied by rectifying the carrier; when the carrier is present, turn-ON bias is applied to Q5. To stop the carrier and turn Q5 OFF, the set and reset inputs are tied together and switched high, forcing both Q and \bar{Q} to go high.

There is no limit to how long the carrier may appear at the transformer, and thus no ON time or duty cycle limitations. The transformer is much smaller than the kind used in a typical transformer drive because it handles 1 MHz instead of the normal 20 kHz. Because it is smaller and has fewer turns, this transformer has less leakage inductance and is less expensive than typical transformer drives.

Care must be taken in winding transformer T1 because any current flowing through the primary-to-secondary coupling capacitance is rectified by the diode bridge (D1-D4) and can cause false triggering of Q5. A common mode immunity of well over 10,000 V/ μ sec can be obtained by winding the secondary with miniature co-ax cable (Belden #8700). One end of the co-ax shield (not both) connects to the source lead of Q5.

Drive signals applied to T1 must also be carefully controlled. To prevent saturation, the carrier supplied to the transformer must have a duty cycle very close to 50%. This is guaranteed, independent of the clock frequency, by using the MC4013 flip-flop (U1) in its divide-by-two mode. This flip-flop also supplies complementary signals with very small overlap to T1, which guarantees a notch-free signal after the diode bridge.

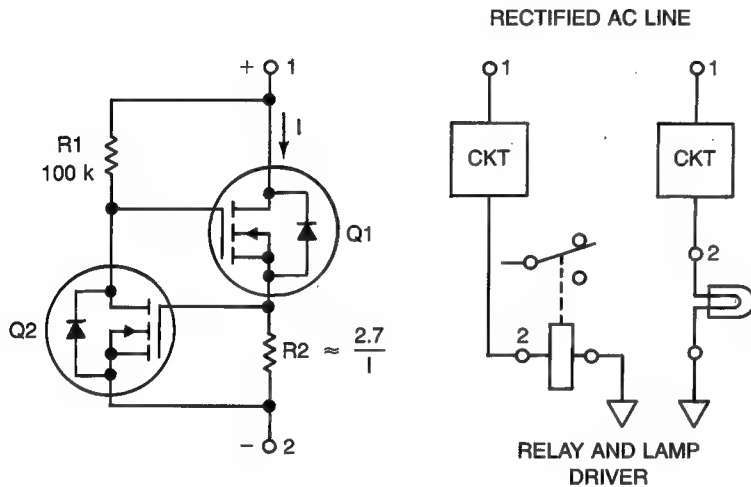


Constant Current, High Compliance
Source/Sink

Richard Walter, Parsippany, NJ

The basic configuration for this constant current source/sink is shown in Figure 1. Initial positive biasing produces current flow in Q1 because its gate is forward biased. When sufficient current (I) flows, the voltage across R2 reaches the gate threshold voltage of Q2, which then conducts enough to force the Q1 gate to supply the current, I. R2 is approximately 2.7/I.

By using a quad TMOS part, such as the MFQ990C, three sections can be paralleled to form Q1 and the fourth becomes Q2. With $R2 = 135\Omega$, this circuit provides a compliance of 90 V at $I \approx 20 \text{ mA}$ and 25°C ambient.



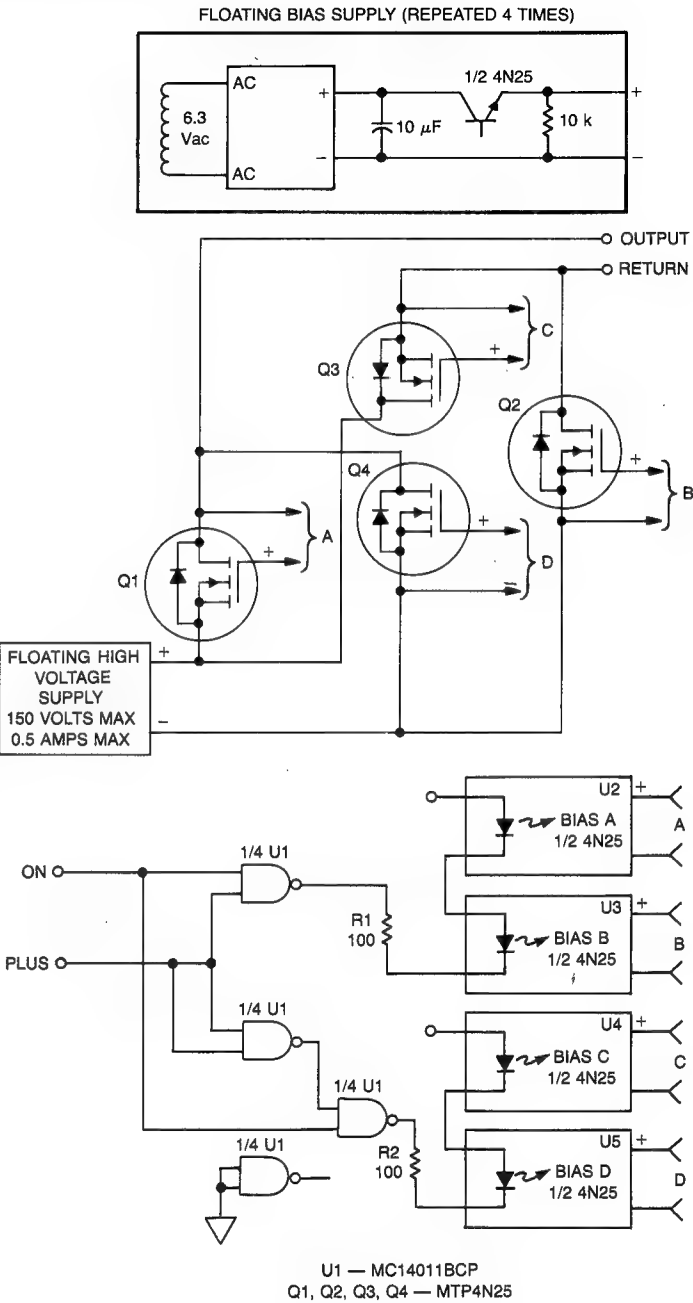
High Voltage Switching Circuit

Mike Willingham, Mansfield, TX

This high voltage switching circuit replaces a mechanical relay that is expensive and has a relatively short life. Although it occupies slightly more space than a relay, the advantage of reliability of the function is desirable. After one year there have been no failures in 15 installations. In contrast, every one of the original mechanical relay installations required service every three months. The cost-to-warranty reduction and increased customer satisfaction have repaid the conversion cost many times. Manufacturing costs have been lowered as well.

In operation, Q1 and Q2 are switched On in pairs, as are Q3 and Q4. Each of the four opto-isolators controls the output of a floating bias supply that rectifies 6.3 V ac and supplies a dc bias to turn ON one of these TMOS devices. A logic command applied to U1 causes the OUTPUT and RETURN of the high voltage power supply to change polarity.

If a logic command is given to turn ON the plus high voltage, opto-isolators U2 and U3 turn ON and opto-isolators U4 and U5 turn OFF. When this occurs, Q1 and Q2 are turned ON and Q3 and Q4 are turned OFF, the return side of the high voltage line is minus and the output is plus. If a polarity reversal is required, the logic input turns ON U4 and U5 and turns OFF U2 and U3, causing Q1 and Q2 to turn OFF and Q3 and Q4 to turn ON.

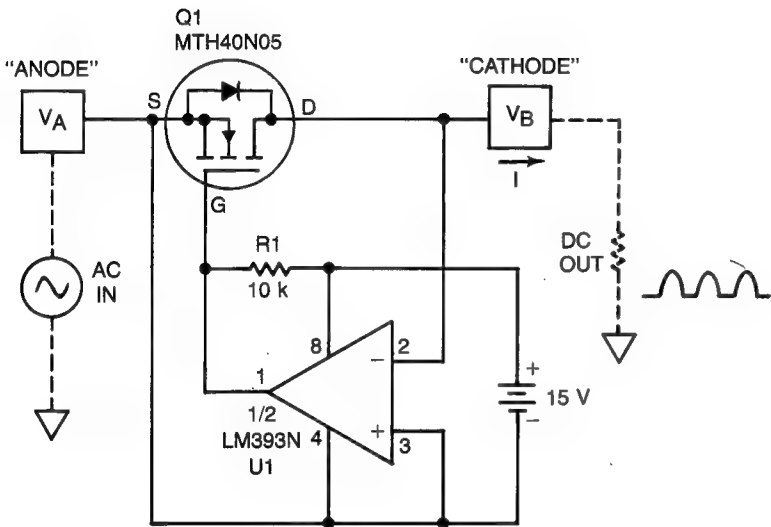


Low Forward Drop Rectifier Circuit

Bruce Rosenthal, Sunnyvale, CA

A TMOS Power FET (Q1) and an LM393 comparator (U1) can be used to provide a high efficiency rectifier circuit, as shown. When V_A exceeds V_B , U1's output goes high and Q1 conducts. Conversely, when V_B exceeds V_A , the comparator output goes low and Q1 does not conduct.

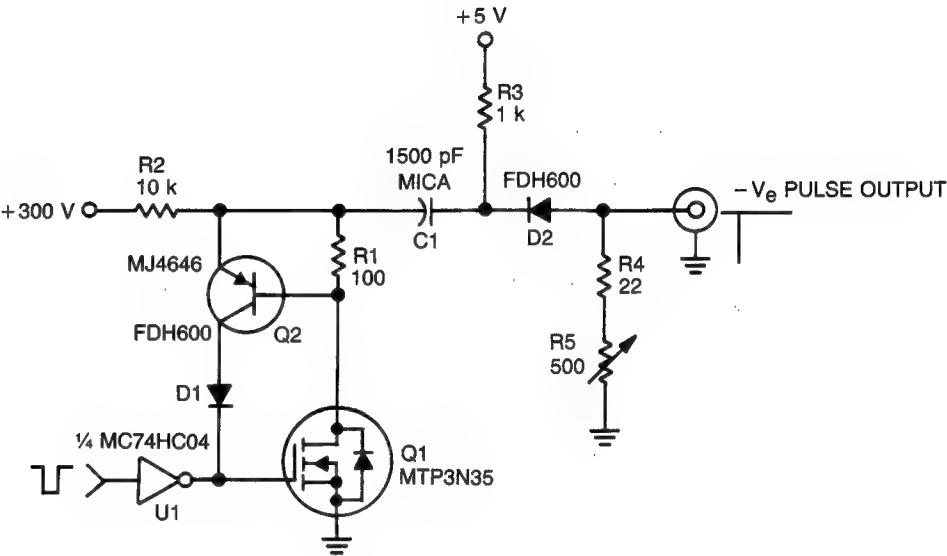
The forward drop is determined only by Q1's ON resistance and current I . The MTH40N05 has an ON resistance of $0.028\ \Omega$; for $I = 10\text{ A}$, the forward drop is less than 0.3 V . Typically, the best Schottky diodes do not even begin conducting below a few hundred millivolts.



300 V Pulse Generator

Daniel Gray, Calgary, Alberta, Canada

In this TMOS pulser, a negative going pulse is applied to U1, a high speed CMOS buffer, which directly drives the gate of Q1, an MTP3N35. (If only a 100 V pulse is required, the MTA6N10 can be used.) The pulse output across R2 is differentiated by R3-C1 and appears as a negative-going spike at the output terminal.

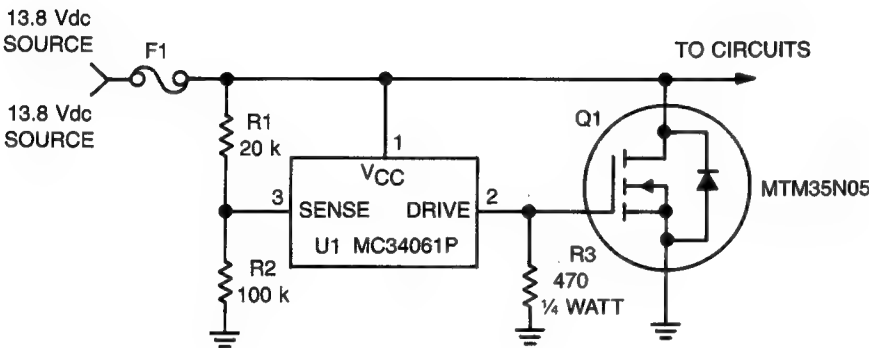


Fast Overvoltage Protection With No Latchup

Charles E. Browder, Ft. Lauderdale, FL

This circuit protects expensive portable equipment against all types of improper hookups and environmental hazards that could cause an over voltage condition. It operates very quickly and does not latchup, that is, it recovers when the overvoltage condition is removed. In contrast, SCR overvoltage circuits can latch and do not recover unless the power is removed.

Here, U1 senses an overvoltage condition when the drop across R1 exceeds 2.5 V. This causes U1 to apply a positive signal to the gate of Q1, turning it ON and shorting the line going to the external circuits. Fuse 1 opens if the transient condition lasts long enough to exceed the its i²t rating.

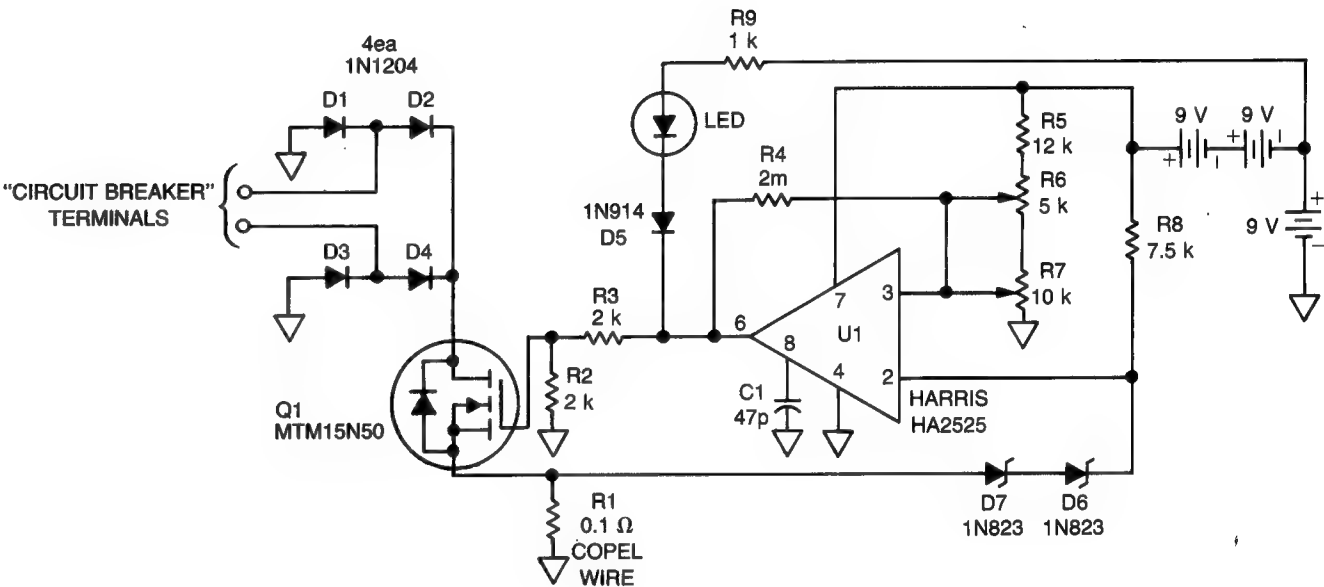


High Speed Electronic Circuit Breaker

D. Newton, Culver City, CA

This 115 VAC, electronic circuit breaker uses the low drive power, low ON resistance and fast turn OFF of the TMOS MTM15N50. The trip point is adjustable, LED fault indication is provided and battery power provides complete circuit isolation. These characteristics allow this circuit breaker to be inserted into a prototype power conditioning system during initial turn-ON and debugging. Circuit response time is close to the limits of the Power FET itself, which is adequate for many bipolar protection tasks.

The two "circuit breaker" terminals are across one leg of a full wave diode bridge consisting of D1-D4. Normally, Q1 is turned ON so that the circuit breaker looks like a very low resistance. One input to comparator U1 is a fraction of the internal battery voltage and the other input is the drop across zeners D6 and D7 and the voltage drop across R1. If excessive current is drawn, the voltage drop across R1 increases beyond the comparator threshold (determined by the setting of R6), U1 output goes low, Q1 turns OFF, and the circuit breaker "opens." When this occurs, the LED fault indicator is illuminated.



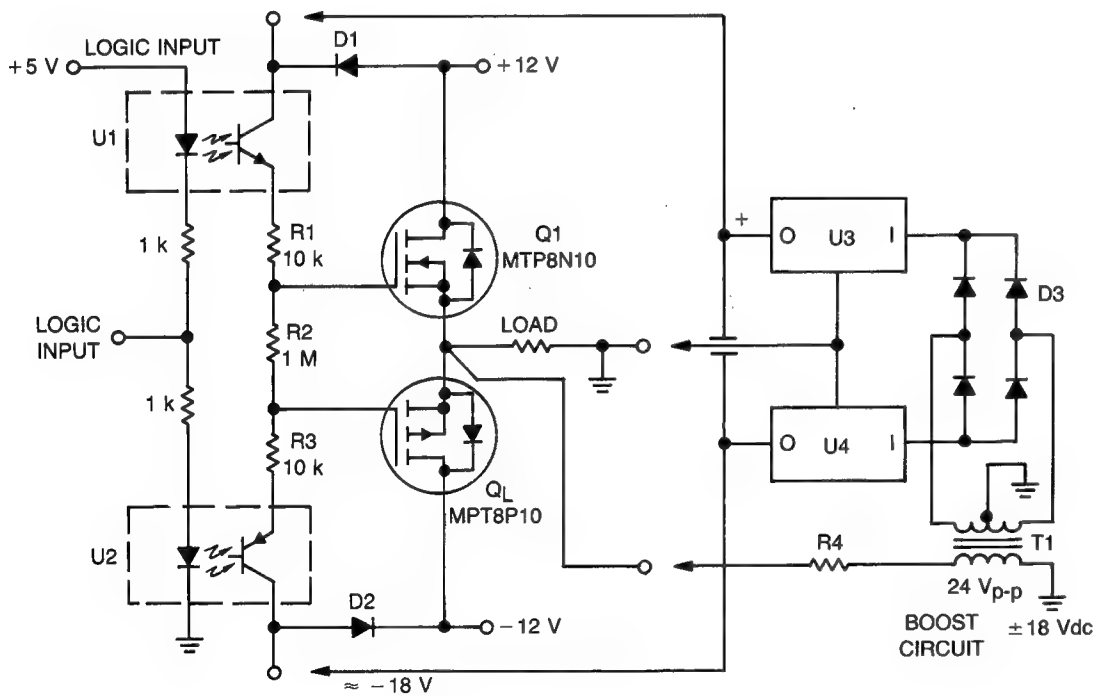
Line Driver Provides Full Rail Excursions

Stan Harrison, Parker, CO

A relatively simple logic signal line driver can be configured using complementary TMOS pairs to achieve full excursions to + and - supply rails.

The logic input is applied to opto-isolators U1 and U2 with, respectively, NPN and PNP emitter follower outputs. Dc balance is adjusted by potentiometer R2. The emitter followers drive the gates of Q1 and Q2, the complementary TMOS pairs. With a ± 12 V supply, the swing at the common source output point is about 12 V peak-to-peak.

By adding a ± 18 V boost circuit, as shown, the output swing can approach the rail swing. This circuit applies the output to transformer T1, which is rectified by diode bridge D3, regulated by U3 and U4, and then applied to the collectors of U1 and U2. Diodes D1 and D2 are forward-biased when 12 V supplies are used, but they are back-biased when the ± 18 V boost is used.



Since any TMOS complementary pair may be used, a method for calculating the load is given by:

$$\text{Load voltage} = .714 \times 12 \text{ V} = 8.6 \text{ V RMS}$$

From the FET derating curves, determine the maximum operating current. For the MTP8N10 @ 25°C, use 8 A.

$$8 \text{ A} \times 0.5\Omega = 4 \text{ V drop}$$

$$8.6 - 4 \text{ V drop} = 4.6 \text{ V RMS across } R_{\text{LOAD}} @ 8 \text{ A}$$

$$V = IR$$

$$4.6 = 8R$$

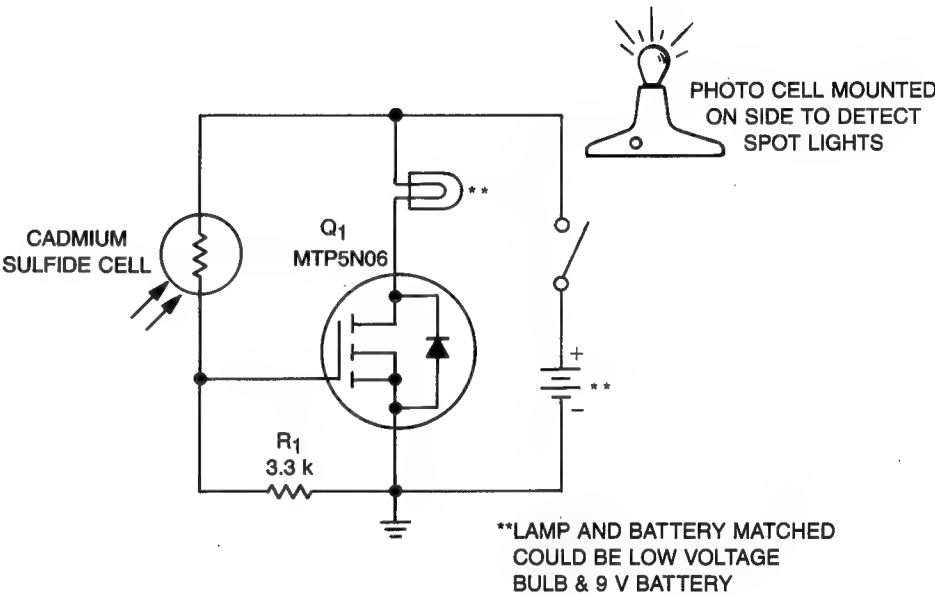
$$R = 0.575\Omega, \text{ minimum load impedance or resistance}$$

Light-Controlled Lamp Switch

Dennis Baldridge, Bourbonnais, IL

Our school drama department needed lamps that automatically went ON and OFF when spot lights did the same. Lamp switching had to be wireless, durable, dependable, simple and low cost.

With stage and spot lights OFF, very little light falls on the CdS photocell, so its internal resistance is several megohms and R1 keeps the gate of Q1 at nearly zero volts, which keeps it OFF. When a spot or stage light hits the photocell, its resistance drops to several hundred ohms, raising Q1's gate voltage, which turns it ON and applies power to the lamp.



**LAMP AND BATTERY MATCHED
COULD BE LOW VOLTAGE
BULB & 9 V BATTERY

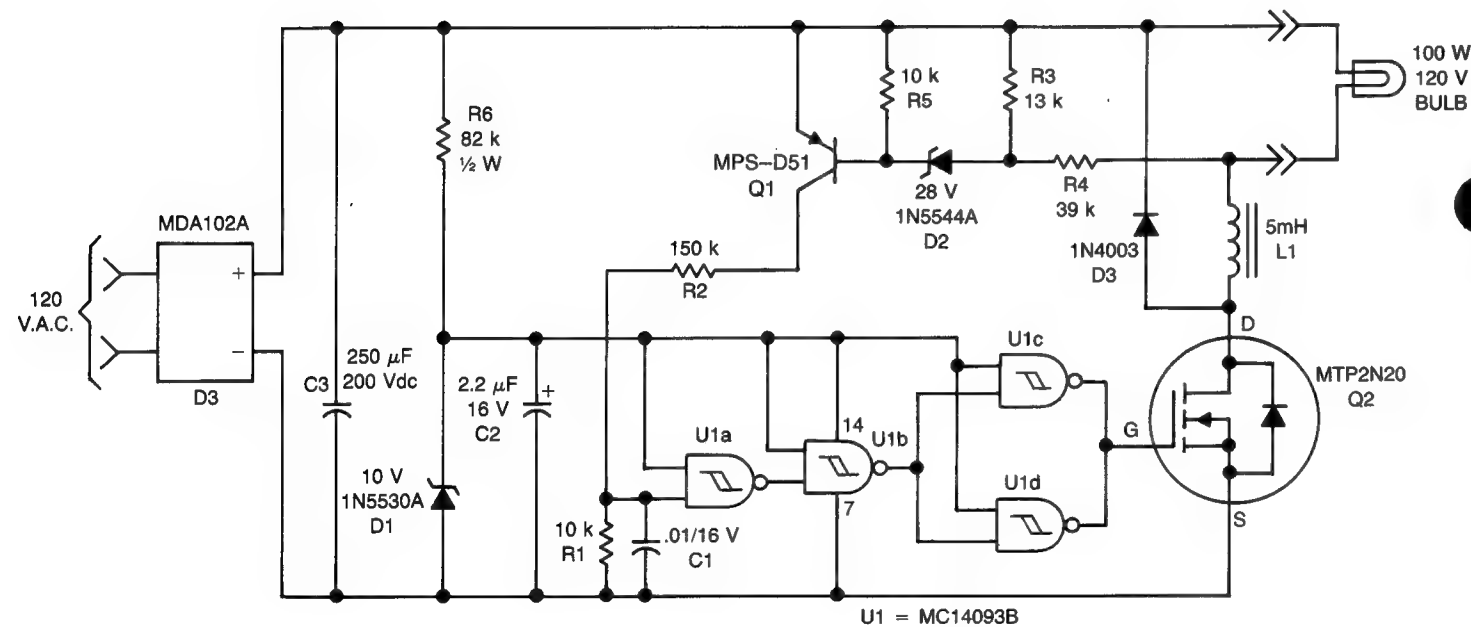
Illumination

Machine Vision Illumination Stabilizer

Scott Juds, Everett, WA

Variation of machine vision system illumination with line voltage is one of the more significant problems to contend with in the industrial environment. Dropouts from large machines starting or just general variation throughout the day can affect illumination and detection reliability. This switching regulator circuit solves this illumination stabilization problem.

The combination of Q1, Q2 and U1 form a hysteresis oscillator to stabilize lamp illumination. In operation, full wave bridge D3 operates directly from the ac line to supply unregulated dc to the lamp and also to the 10-V zener that provides power to the quad CMOS Schmitt trigger, U1. When the lamp supply exceeds 115 V, Q1 is turned ON, charging C1 through R2 to raise the input to U1a past the positive-going logic threshold. This drops the output voltage at U1c and U1d, which drives the gate of Q2, turning it OFF. Current then decays through the lamp, L1 and D3 until the lamp voltage falls below 115 V, at which time Q1 turns OFF and the cycle repeats.



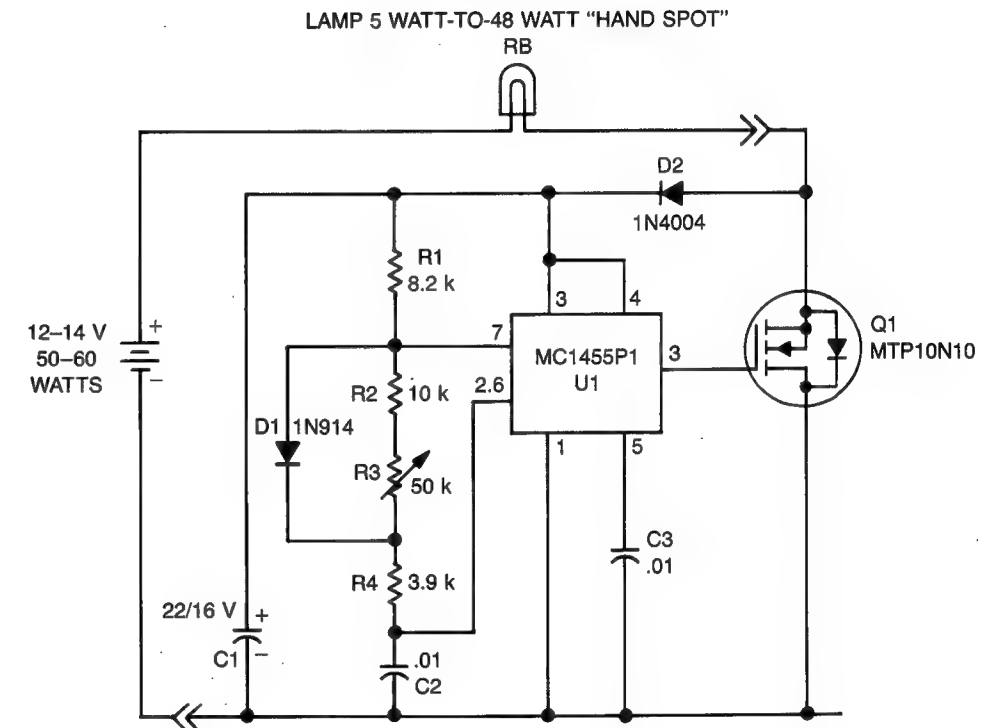
Illumination

DC Lamp Dimmer

Mark Molnar, Bellville, OH

A low power, low cost dc lamp dimmer for a two-wire portable "flashlights" can be realized with little or no heatsinking. In addition, a single potentiometer, R3 adjusts lamp brightness.

Battery power is stored in C1 for U1, which is a free-running multivibrator whose frequency is determined by R1, R2, R3, R4 and C2. U1 drives the gate of Q1, turning it and the lamp ON and OFF at a rate proportional to the multivibrator duty cycle.



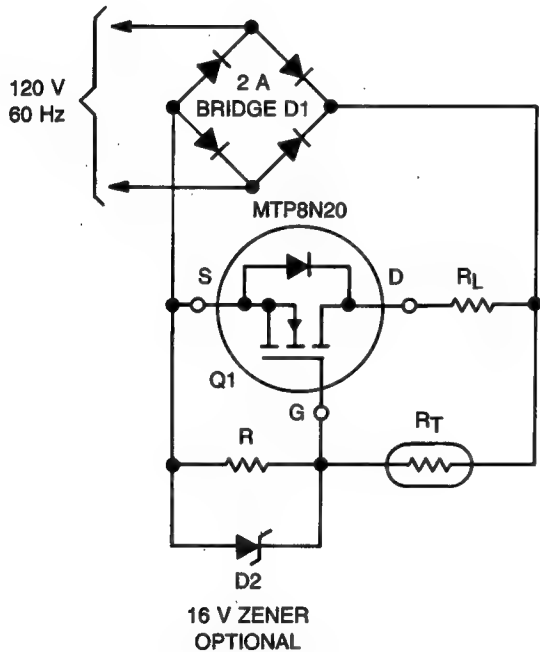
Lamp Life Extender
B. E. Anderson, Rockville, MD

Lamp life can be extended by improving the conditions under which its filament is operated. This includes eliminating the inrush overcurrent surge and reducing the mechanical stress (vibration) on the filament caused by an alternating current source.

The circuit shown controls the inrush current to the lamp without the 10 to 15 times rated current surge that normally occurs when power is applied to a "cold" lamp. It does so by adjusting the inrush current over time to the inverse of the value normally experienced.

RL is a standard tungsten lamp in the range of 15 to 250 W, R is 10 K Ω and RT is a negative temperature coefficient resistance that is initially 1.65 M Ω and decreases, by self-heating, to 150 K Ω in approximately 0.5 sec. Use of the TMOS device allows high ohmic values for R and RT, keeping drive power at a negligible level.

This circuit has a number of advantages: very low power dissipation, long life and low cost components, no significant effect on lamp ratings, negligible effect on efficiency, negligible RFI and can be used in hazardous environments.



Safety Shutdown Monitor
Buddy J. Cook, Tigard, OR

Many industrial systems contain a safety shutdown circuit that takes control of equipment to prevent a safety hazard. The circuit shown here monitors such a safety shutdown circuit to ensure that it will operate properly, if necessary.

This circuit operates with several different loads and source voltages, either ac or dc supply; it also provides isolation and load protection if a circuit malfunction occurs.

The monitor is placed across across load switch S1, which turns on the power to load L1. Fuse F1 is selected to open before a failure could energize the load, because any failure in the monitor could turn on the load.

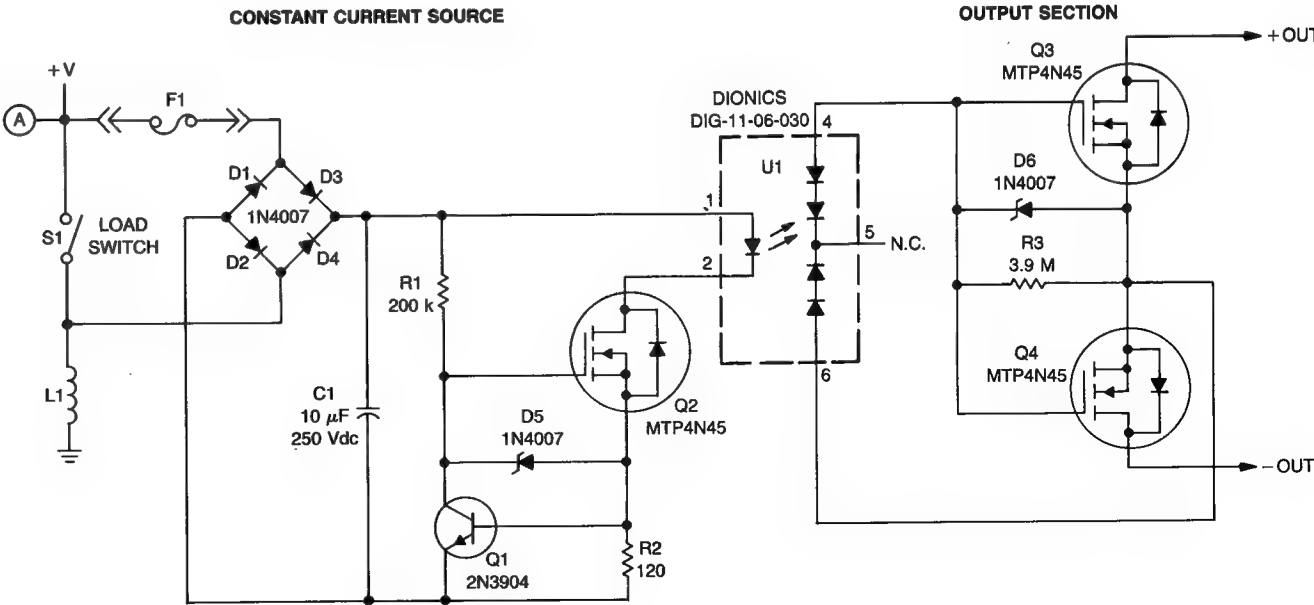
In operation, a TMOS-controlled current source, consisting of Q1, Q2, R1, R2 and D5, supplies a constant trickle current through L1. S1 is normally open, so no power is applied to the load. An external positive voltage is applied at point A, causing current flow through D3, U1, Q2, R2, D2 and the load. As the supply voltage begins to rise, Q2's gate rises at the same rate. When the gate-to-source voltage reaches the gate threshold, Q2 begins to conduct and the drain-to-source current begins to increase. Transistor Q1 conducts when the drop across R2 reaches 0.6 V, forcing the gate of Q2 more negative, which regulates its gate-to-source voltage and provides a constant current. This constant current source provides a fixed current in the opto-isolator (U1), so a constant open circuit voltage is presented to the output section.

The open circuit voltage output of U1 is sufficient to drive the gates of Q3 and Q4 past their respective turn-on thresholds. A single Power MOSFET can switch a dc voltage, however two such devices are required for ac.

The parasitic diodes are used to an advantage when switching ac. When a positive voltage is applied to the drain of Q3, its parasitic diode is back-biased. However, U1 produces a voltage that is positive relative to the source, so Q3 turns ON. Q4 is tied to Q3, so the current through Q3 must flow into the source of Q4. Therefore, Q4's parasitic diode is forward-biased, completing the circuit loop. When the polarity is reversed, the parasitic diodes are again forward-biased.

Zener diodes D5 and D6 protect the TMOS FETs from transients that could cause gate-to-source damage. R3 improves turn-off time by providing a lower gate resistance discharge path.

Two conditions cause the circuit to indicate a break in monitor current. One is when the current path is interrupted or broken, the second is when S1 is closed, shunting the current source. When the control system operating the switch determines a safety shutdown must occur, it toggles the switch (the switch is actually a redundant series/parallel combination). Since the control system was in an alarm state to turn on the switch, the monitor indication is meaningless. However, if monitor current is lost and the system does not call for a shutdown, an alarm is sounded.



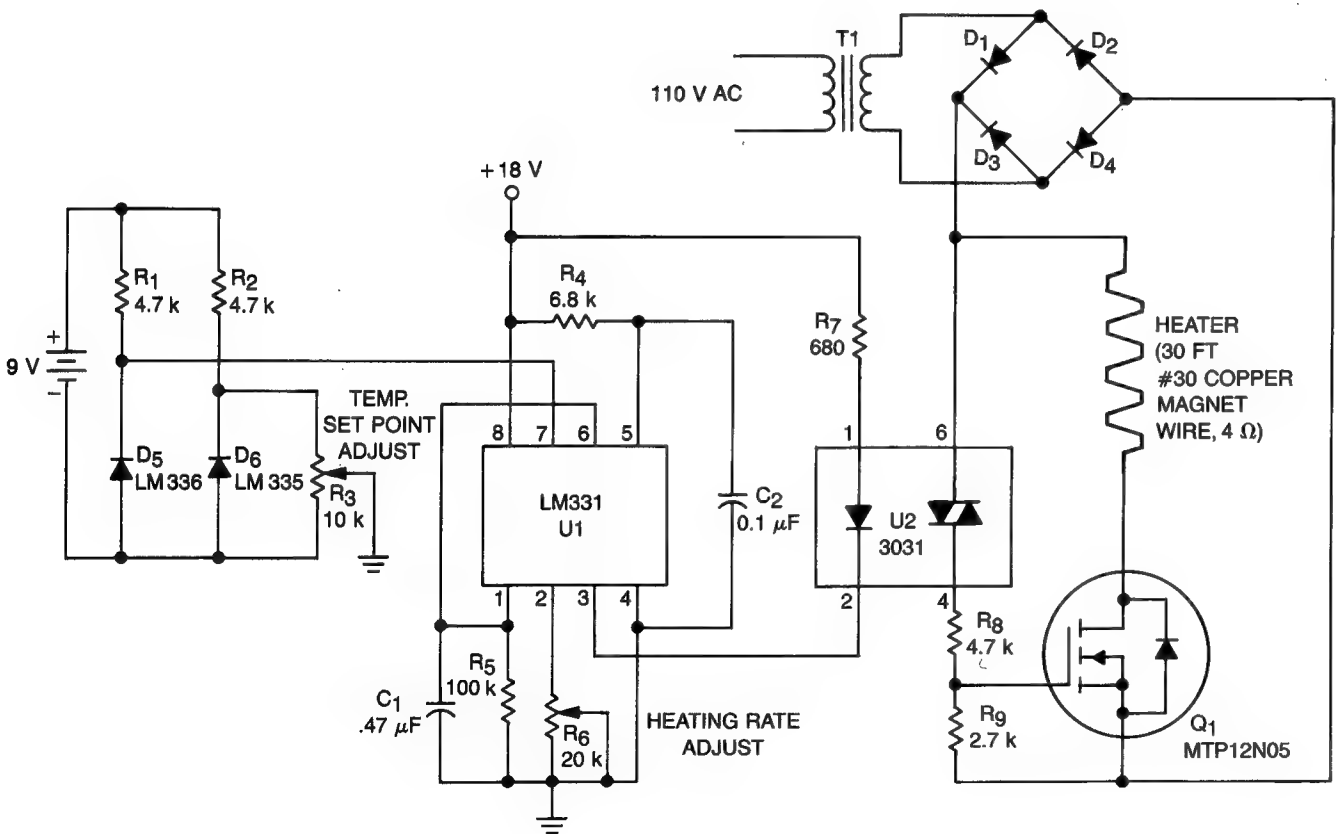
Proportional Temperature Controller

Douglas Jewett, Ann Arbor, MI Third Prize Winner

This temperature controller operates as a "pulse snatching" device, which allows it to run at its own speed and turn ON at the zero crossing of the line frequency. Zero crossing turn-ON reduces the generation of line noise transients.

In this circuit, a TMOS Power FET, Q1, is used to turn ON a chemical reactor's heater, which consists of 20 ft of #30 magnet wire (4Ω) wound tightly on the tapered end of a glass centrifuge tube. To improve heat transfer, D6, an LM335 temperature sensor, is cemented directly to the coil with silver epoxy. By doing this instead of the heating block or oil bath normally used, both heating and subsequent cooling of the reactor are very fast, and limited mostly by the time constant of the sensor itself.

Temperature sensor D6 provides a dc voltage proportional to temperature that is applied to voltage-to-frequency converter U1. Output from U1 is a pulse train proportional to temperature offset that is applied to the input of triac optoisolator U2. The anode supply for the triac is a 28 V peak-to-peak, full wave-rectified sine wave. The optoisolator ORs the pulse train from U1 with the zero crossing of U2's anode supply, supplying a gate turn ON signal for Q1. Therefore, TMOS Power FET Q1 can only turn the heater ON at the zero crossing of the applied sine wave. Maximum temperature is limited by the sensor and the insulation of the wire, which is 130°C for the components shown.



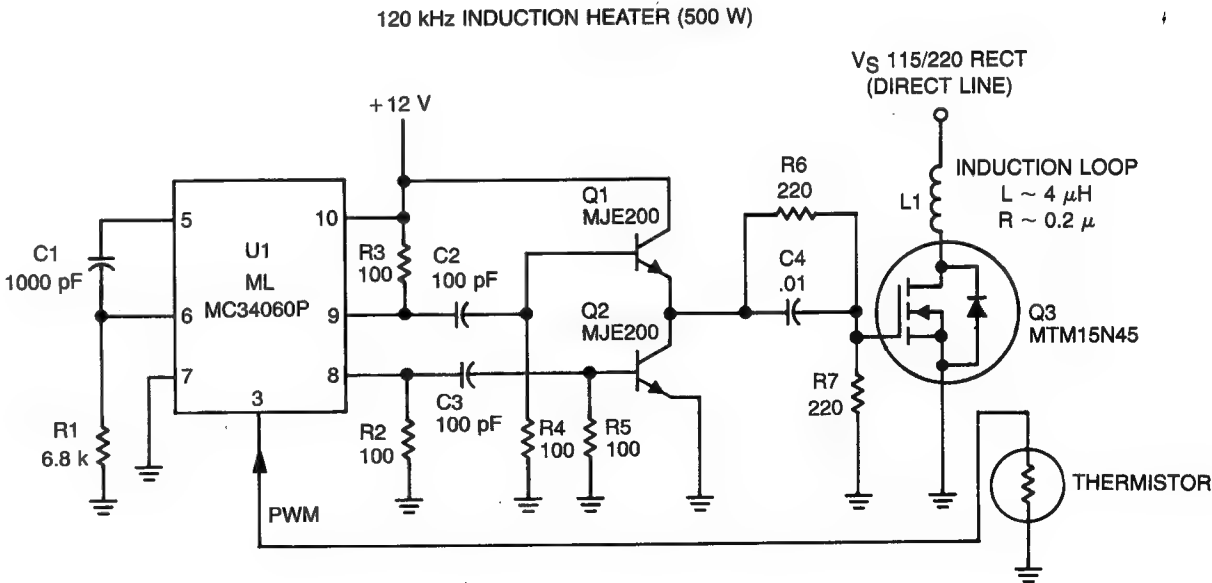
120 kHz, 500 W Induction Heater

Ron Doctors, Santa Barbara, CA

An induction heater for flash heating of conducting solutions using TMOS requires fewer parts and operates at higher speeds than an equivalent bipolar version. Using TMOS also provides the option to increase the output rate without changing the design and allows a modular power concept. In addition, the integral TMOS diode saves an external diode (which is essential because of the possibility of an unloaded induction loop with very high induced flyback voltage).

Variable width pulses with fast rise times are provided by U1, an MC34060 operating at 120 kHz, the optimum frequency for heating aluminum alloy containers. The pulse width is modulated by sensing the temperature of the target with a thermistor, using its negative temperature coefficient to change pulse duration. The MC34060 produces output pulses that are ac-coupled to push-pull MJE200 transistors (Q1 and Q2). This provides the current needed to ensure fast switching of the MTM15N45 TMOS Power FET (Q3).

Estimated efficiency is 80%, based on switching losses and an R_{ON} of 0.4Ω (max). The MTM15N45, with maximum ratings of 15 A and 450 V, was chosen because the induction heater might be operated from either 115 or 220 V sources. A modest heat sink is required because 100 W is dissipated in the power FETs at a full output power of 500 W.



TMOS Sonar Transducer/Switch

Russell Thynnes, Seattle, WA

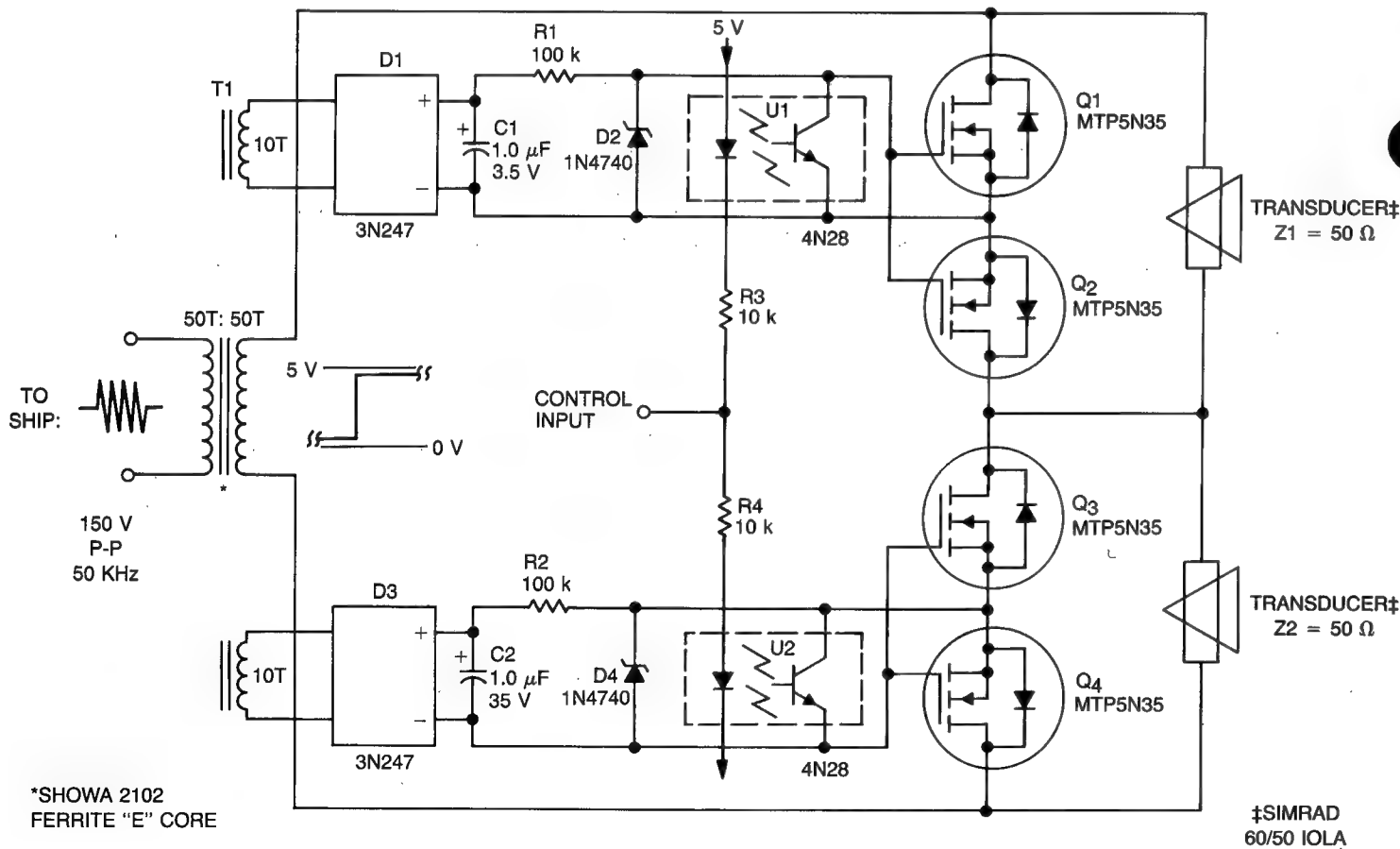
Submersible sonar positioning apparatus generally consists of dual-opposed ultrasonic transducers, alternately excited, with return signals processed and displayed for observation and measurement. Typical transmitter frequencies range from 50 to 200 kHz and pulse widths may be varied from 0.3 to 5 msec, depending on depth and resolution requirements.

In operation, a pulse generated in the ship is sent to the Transducer/Switch via a coaxial transmission line. The TMOS Transducer/Switch accepts the pulses and alternately selects either of two transducers to transmit and receive sonar signals.

The input to the Transducer/Switch is transformer T1 that provides isolation and impedance matching. Turns ratio of the secondary windings depends on the peak-

to-peak amplitude of the transmitter output into the specified load. The transmitted pulse that appears on the secondary winding charges capacitors C1 and C2 through bridge rectifiers D1 and D3. Zener diodes D2 and D4 limit TMOS gate bias to 12 V; R1 and R2 limit discharge current from C1 and C2.

The square wave control input is applied to opto-isolators U1 and U2 through resistors R3 and R4. If the control input is 0 V, U1 is activated, when it changes to +5 V, U2 is activated. When U1 is activated, it saturates and reduces the gate bias to zero, turning Q1 and Q2 OFF. Q3 and Q4 remain ON, effectively shunting transducer Z2. When U2 is activated, it saturates and reduces the gate bias to zero, turning Q3 and Q4 OFF. Q1 and Q2 remain ON, effectively shunting transducer Z1.



Magnet Current Regulator

Steven Young, Menlo Park, CA

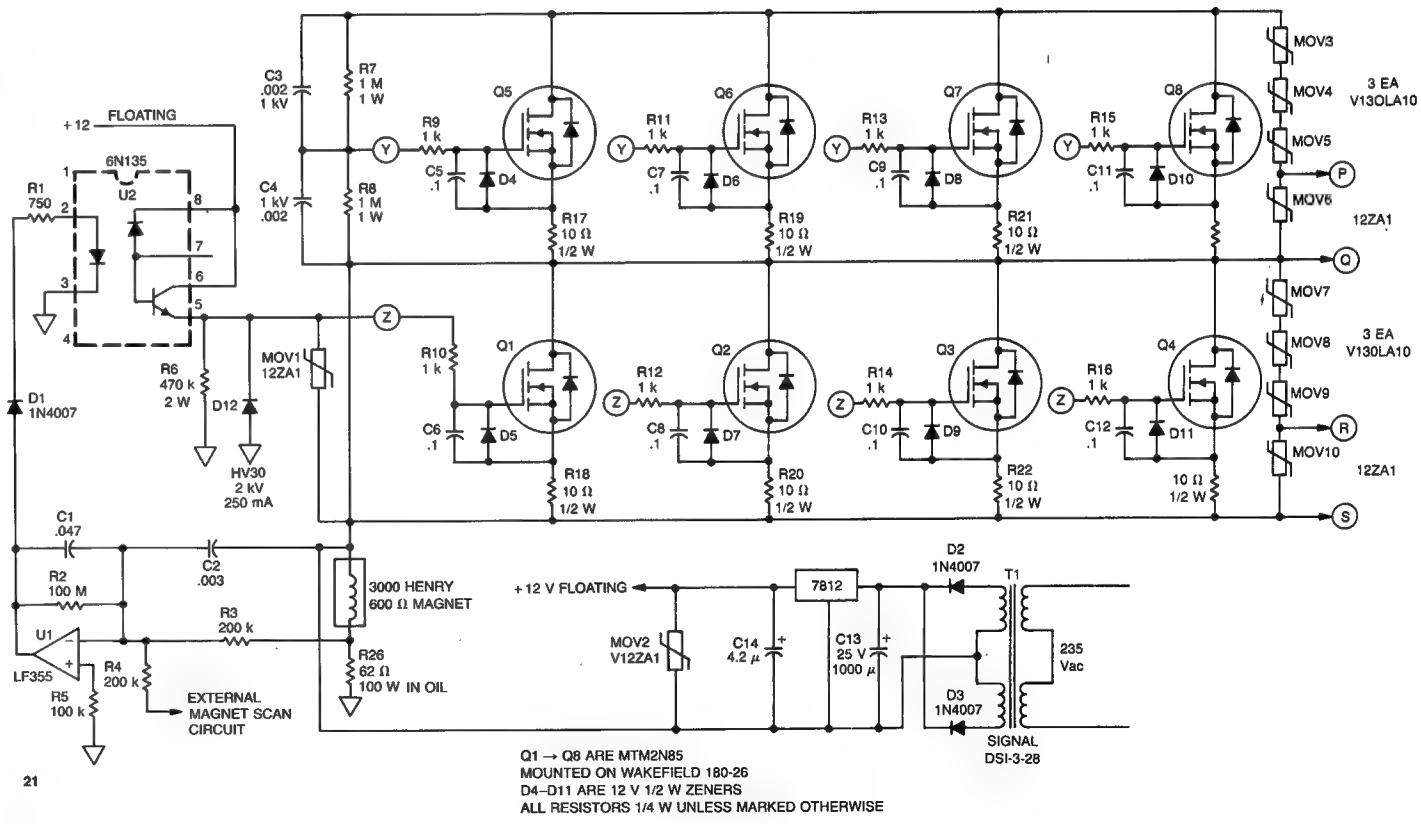
Eight TMOS devices replaced three vacuum tubes (\$1000 a matched set) in a magnet current regulator of a 20-year old mass spectrometer. Power MOSFETs were used because they are cost effective and reliable, and essentially no changes were required for the 1200-V, 1-A power supply and high impedance electromagnet. Previous designs, using bipolar transistors, required 20 devices and failed frequently.

The magnet is 600Ω and 3000H; it requires 700 V for full field of 16,000 gauss and is scanned slowly from high field to low field about once a minute.

Q1 through Q8 form a "totem pole" regulator with Q1-Q4 as a master and Q5-Q8 as a slave. Current passing through the magnet generates a feedback voltage across the R26 reference resistor. This feedback voltage is compared with the programming voltage by U1, which in turn drives the opto-isolator (U2) that varies the gate bias to Q1-Q4.

Because of the "totem pole" arrangement, the inductance of the magnet and the high drain-to-gate capacitance of Q1-Q8, serious oscillation problems can be encountered. This is solved by shunting a 0.1 mfd capacitor from source-to-gate of each TMOS device. It slows down the circuit, but is no problem in this application.

An optional digital protection circuit monitors the magnet current regulator and shuts OFF the 235 V ac if there is a problem.



200 V DC Piezoelectric Gas Valve Switch

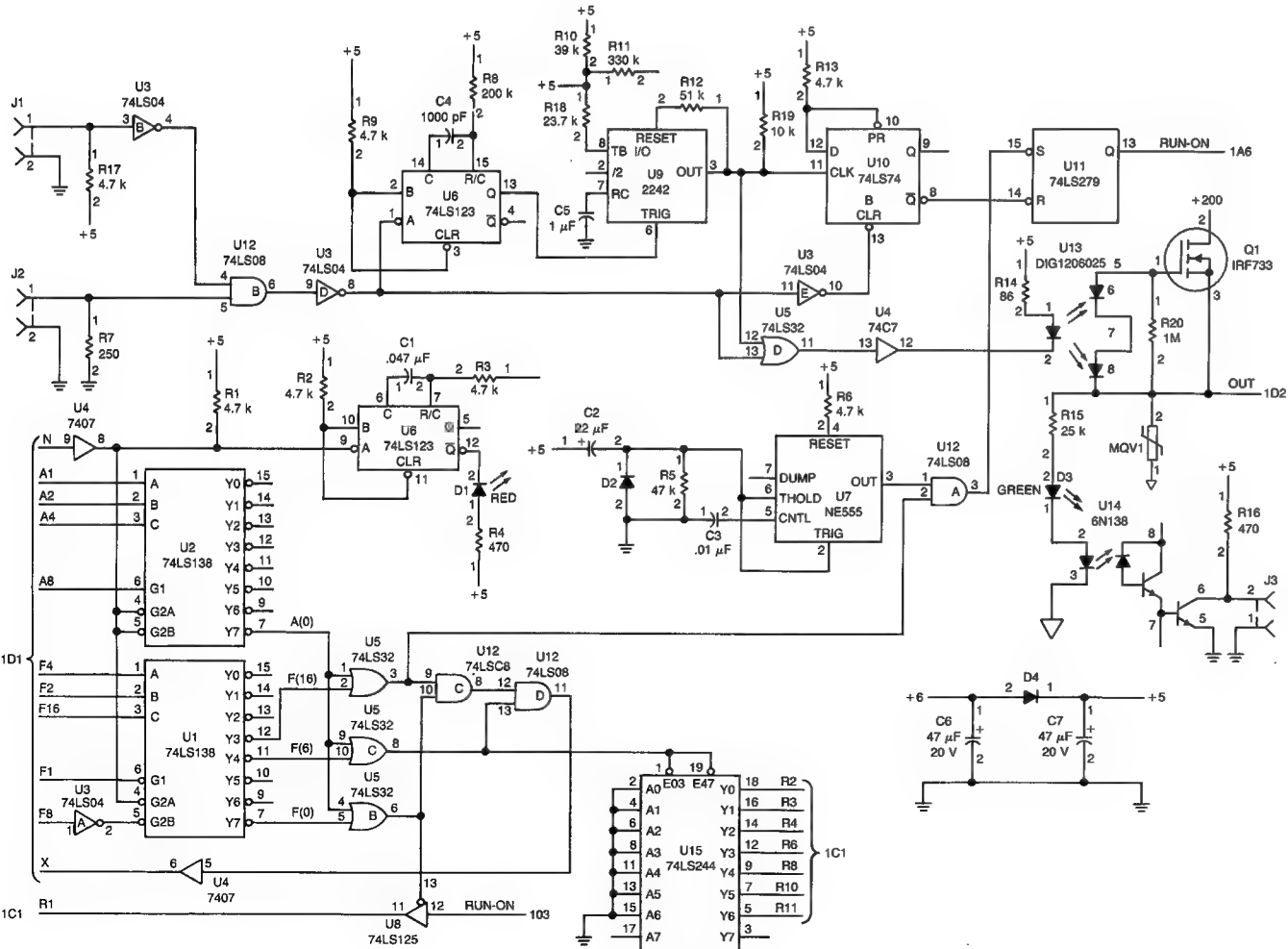
Mark Strauch, Livermore, CA

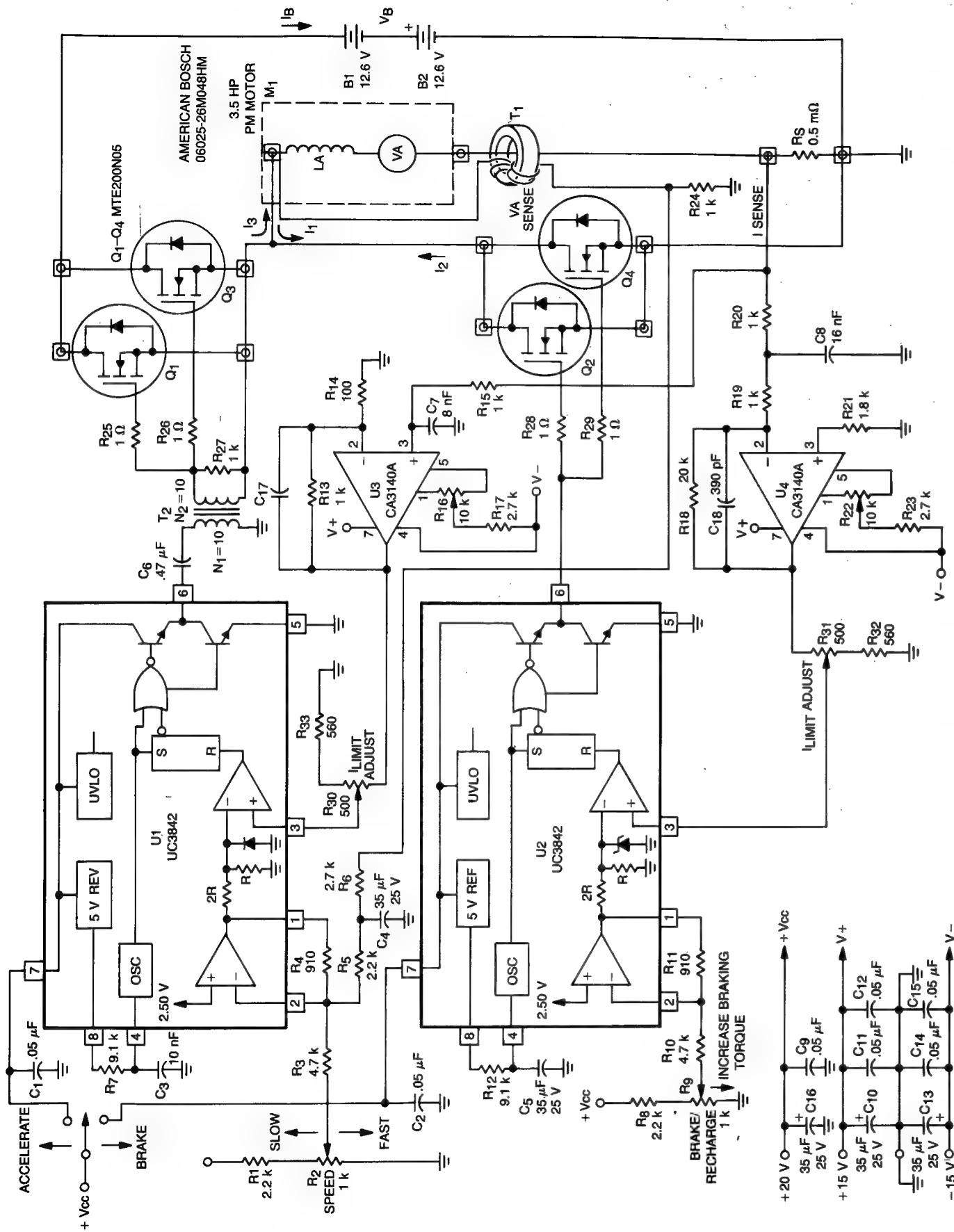
Under TTL command, this module switches 200 V to a piezoelectric valve that controls the supply of gas to a neutral beam accelerator. The switch module consists of three sections as outlined in the schematic: 1) CAMAC interface, 2) power switching, 3) run-on protection.

The CAMAC interface, ICs U1 through U6, U8 and U12, is an IEEE standard. It provides an interface between an "instruction bus" and the module. Only two commands are recognized: READ FAULT and RESET FAULT. These circuits are not involved in power switching.

U13 is a opto-isolator with a single LED and two isolated photosensors that are externally connected in series; it provides a floating gate drive signal to Power FET, Q1. When turned ON, Q1 sources 200 V off the board (accelerator connection "OUT") to drive a piezo-electric valve. MOV1 provides needed transient protection because the distance between Q1 and the load is over 200 feet. Isolator U14 drives provides an isolated output that indicates Q1's operation. The 200 V supply is completely isolated from control power.

For safety considerations, it is important that the module protect itself against timing system failures that may result in run-on (continuous gas flow). Therefore, input J1 is an enable signal and J2 is the timing system signal. ICs U6 and U9 through U11 qualify the timing signal against an internally triggered timer. Timing requests in excess of internal limits result in termination of drive to Q1.





Motor Speed Control

Back EMF PM Motor Speed Control

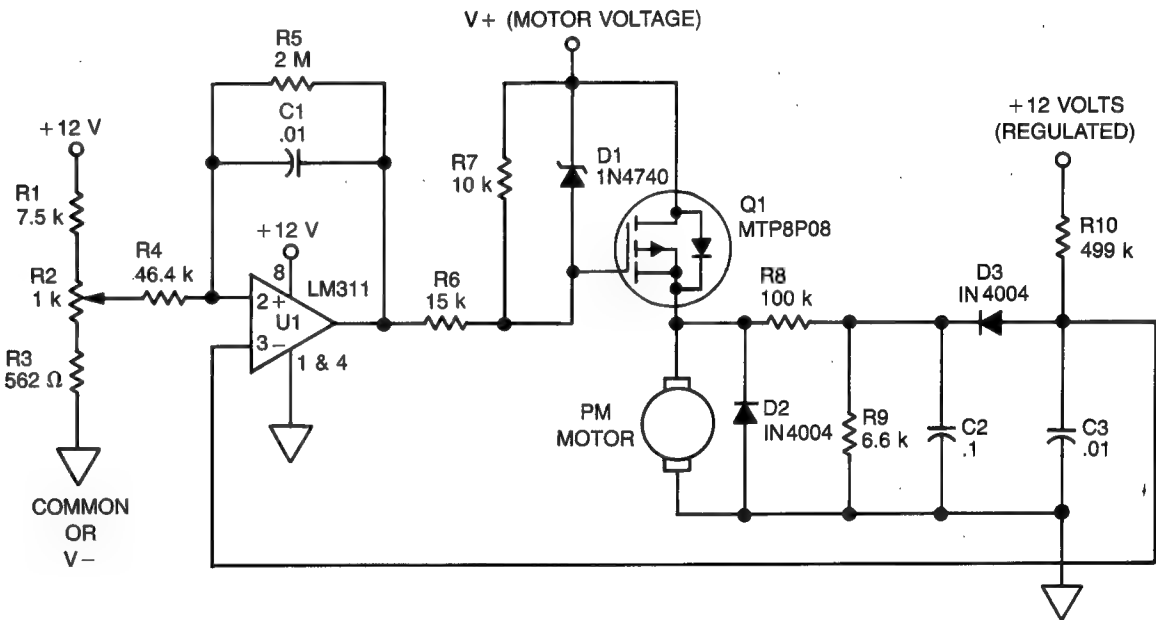
Jim Alleman, Houston, TX

Use of power MOSFETs allows a direct interface between logic and motor power, which permits circuit simplicity as well as high efficiency. This speed control circuit can be packaged on a 22-pin, double-sided, 3.5 X 4-in. p.c. board.

A 12 V control supply and a TRW BL11, 30 V motor are used; with minor changes other motor and control voltages can be accommodated. For example, a single 24 V rail could supply both control and motor voltages. Motor and control voltages are kept separate here because CMOS logic is used to start, stop, reverse and oscillate the motor with a variable delay between motor reversals.

Motor speed is established by potentiometer R2, which applies a corresponding dc voltage to the + input of comparator U1, whose output is then applied to TMOS device MTP8P08 (Q1). Zener diode D1 limits the drive to Q1. The output of Q1 drives the permanent magnet motor.

Back EMF is obtained from the motor via the network consisting of R8, R9, R10, C2, C3 and D3; it is applied to - input of comparator U1.



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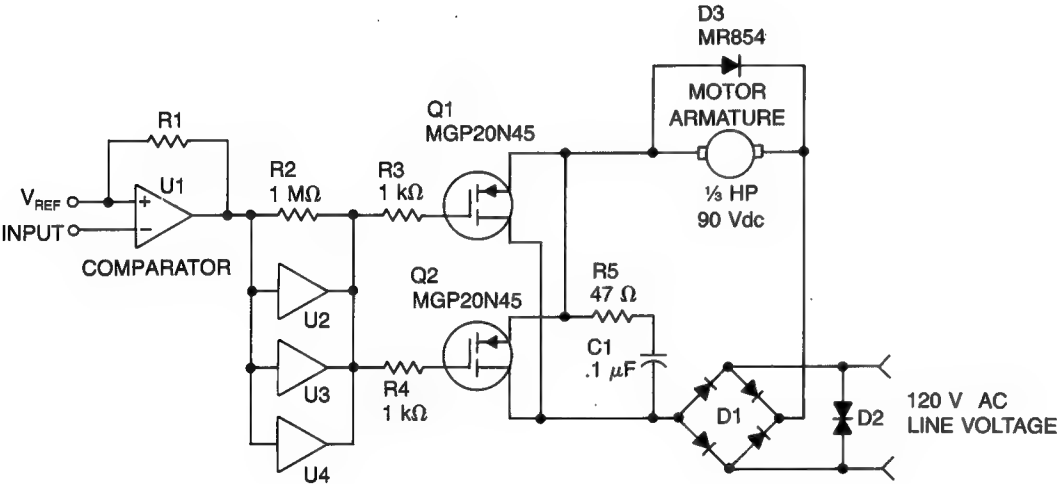
Motor Speed Control

PWM Motor Speed Control

Robert Ritzsche, Chaska, MN

Speed control is accomplished by pulse width modulating the gates of two MGP20N45 TMOS devices. Therefore, motor speed is proportional to the pulse width of the incoming digital signal, which can be generated by a microprocessor or digital logic.

The incoming signal is applied to comparator U1, then to paralleled inverters U2, U3 and U4 that drive the two TMOS devices, which, in turn, control power applied to the motor armature. Bridge rectifier D1 supplies full-wave power that is filtered by R5 and C1. Free-wheeling diode D3 (MR854) prevents high voltage across Q1 and Q2. A back-to-back zener diode, D2, protects against transients and high voltage surges.



Power Sources

High Efficiency, Off-Line Switching Power Supply

Marek Gajenski, Woodland Hills, CA Third Prize Winner

This multi-output, off-line SMPS uses a full-cycle, push-pull 30 kHz converter preceded by a buck-type pre-regulator that is duty cycle modulated at 200 kHz. Efficiencies of 90% may be achieved with this circuit.

The power supply has a number of significant features. Inherently low output noise and low output impedance of the full-cycle converter allows use of much smaller filter capacitors than those of a duty cycle modulated converter. Redundant shutdown prevents abnormal behavior at both output and input in case of switching transistor failure. Core saturation of T1 is completely eliminated by free-running switching that ensures automatic duty cycle symmetry compensation, which accommodates even badly mismatched switching transistors. Using diodes D1 and D2 to hold the center tap of driver transformer T2 close to the converter's return potential eliminates cross-conduction inducing gate drive overlap. And, no snubber is required.

Absence of a large filter capacitor after the buck regulator's inductor (L1) prevents excessive energy storage in T1's inter-winding and intra-winding capacitance. At the same time, it does not add a second-order pole at lower frequencies, which simplifies loop compensation. Also, the load capacitance is transformed into the primary and serves as an energy storage element during the OFF cycle.

Because of its superior ON-resistance and faster switching times, the buck pre-regulator, Q3, uses an N-Channel MTH7N45 rather than a P-Channel device. Referred to ground, it is conveniently driven by a simple 4050 CMOS driver. For higher current applications, a parallel connection of two MTH7N45s may be used, which is still less costly than an equivalent TO-3 device.

Q4 and Q5 form a synchronous rectifier for the +5 V output. Up to 20 A, these devices offer lower dynamic and static losses than conventional Schottky diodes. For up to 50 A, the MTE200N05 can be used; it has only 9 mV On-resistance and is better than equivalent Schottky diodes.

Input/output ground isolation for the error voltage is accomplished with a small transformer, T3, using a 4041 push-pull driver on its primary side and a synchronous rectifier consisting of MPF910 TMOS Power FETs (Q6 and Q7). Unlike opto-isolators, the transfer function of such a module is insensitive to temperature and production tolerances and remains very close to unity, which introduces negligible error to output voltage tolerance.

35

Power Sources

Self Oscillating, Flyback Switching Converter

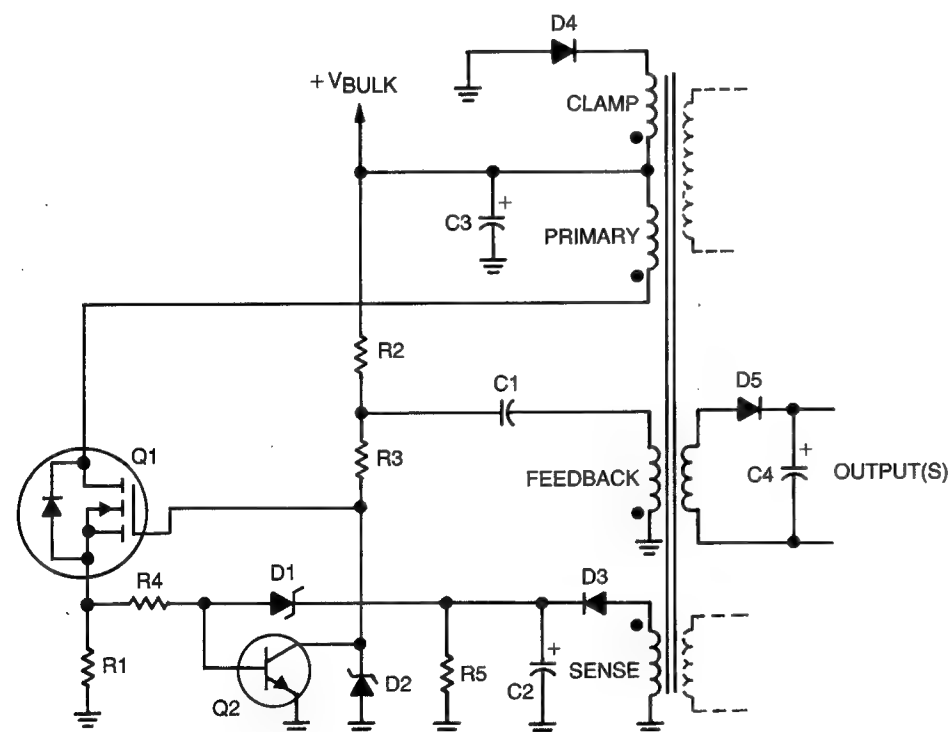
Douglas Glenn, Lewisburg, TN

In-phase transformer windings for the drain and gate of TMOS Power FET Q1 cause the circuit to oscillate. Oscillation starts when the feedback coupling capacitor, C1, is charged from the supply line via a large resistance, R2. R3 limits the collector current to Q2. During "pump-up", the ON time is terminated by Q2, which senses the ramped source current of Q1. C1 is charged on alternate half-cycles by Q2 and forward-biased zener D2.

When the regulated level is reached, forward bias is applied to Q2, terminating the ON time earlier at a lower peak current. When this occurs, the frequency increases in inverse proportion to current, but the energy per cycle decreases in proportion to current squared. Therefore, the total power coupled through the transformer to the secondary is decreased.

Regulation is provided by taking the rectified output of the sense winding and applying it as a bias to the base of Q2 via zener D1. The collector of Q2 then removes drive the gate of Q1. Therefore, if the output voltage should tend to increase, Q2 removes the drive to Q1 earlier, shortening the ON time, and the output voltage will remain the same.

Dc outputs are obtained by merely rectifying and filtering secondary windings, as done by D5 and C4.



Power Sources

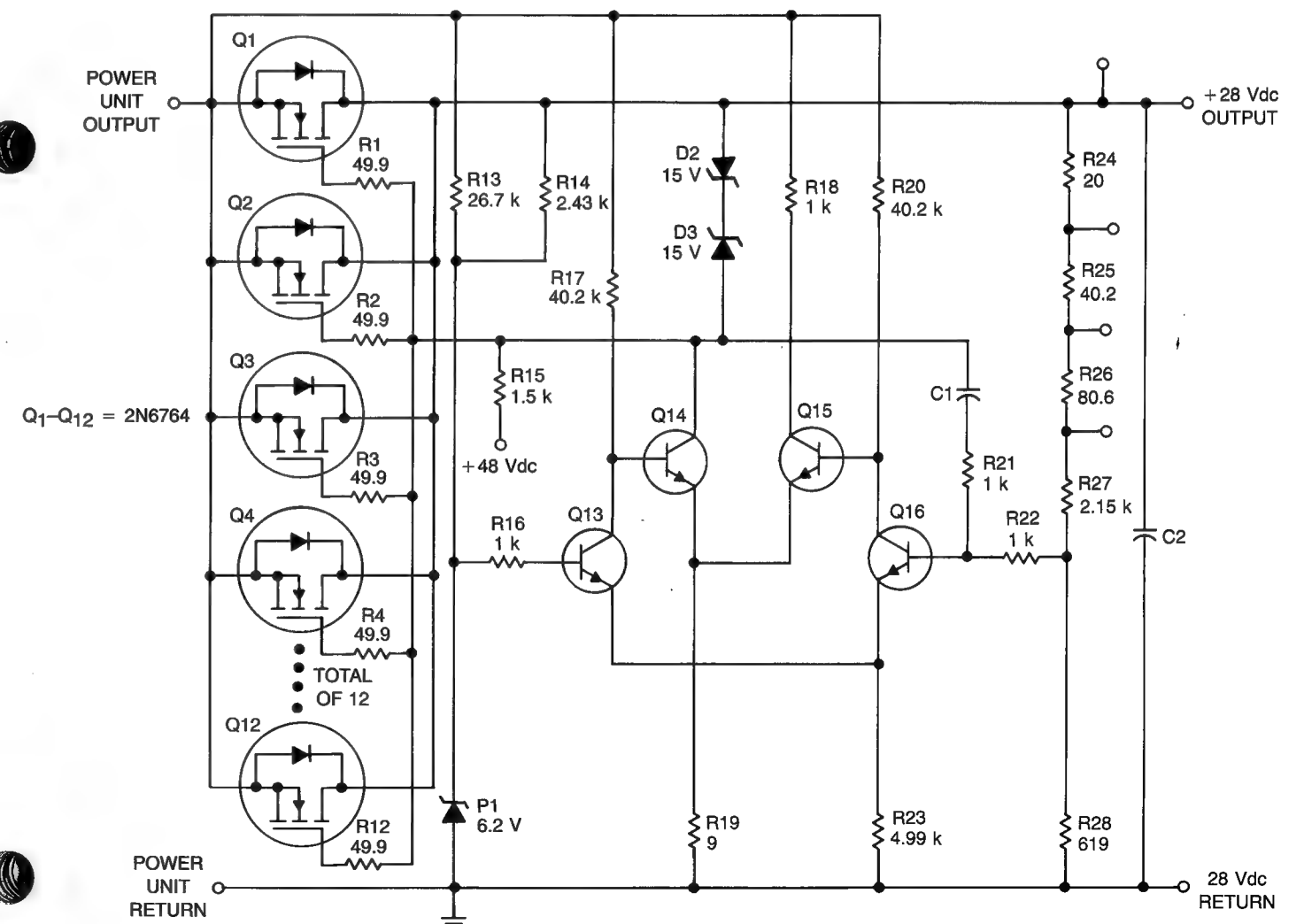
Radiation-Hardened, 125 A Linear Regulator

Tom R. Seaton, Portland, OR

Intended for extreme temperature, radiation-hardened environments, this linear supply is capable of supplying 28 V dc at 125 A from an ac-driven power unit. A linear approach was chosen for its inherent low ripple and noise, simplicity, reliability, wide bandwidth and also to provide the instantaneous current required to clear shorts.

In operation, power supply output voltage is sensed by the voltage divider consisting of R24 to R28 and fed to one input of a discrete differential amplifier composed of Q13 through Q16. The other input of the amplifier is connected to a radiation-hardened zener diode, D1. Local feedback using R21 and C1 produces gain and phase shift that are independent of individual component parameters, which provides stable operation into the required loads.

Clamped by back-to-back zener diodes (D2 and D3), the differential amplifier drives the gates of the 12 paralleled TMOS devices through 49.9v series resistors, which eliminate high frequency oscillations. The large number of MOSFETs insures sufficient current to clear output short circuits even under high temperature where their internal resistance increases and current-handling capacity is reduced. To insure reliable turn-on of the TMOS devices under all conditions, drive circuits are powered by an external +48 V dc supply. In this way, TMOS gates can be driven to +15 V dc relative to their sources. If the circuit is subjected to radiation, the gate threshold voltage of the TMOS becomes more negative, and can even reverse polarity with sufficient dosage. To handle this situation, the TMOS gates can be driven to -15 V dc.



Power Sources

Low Cost, Very Low Dropout Linear Regulator
Aubrey Elms, Marlboro, MA

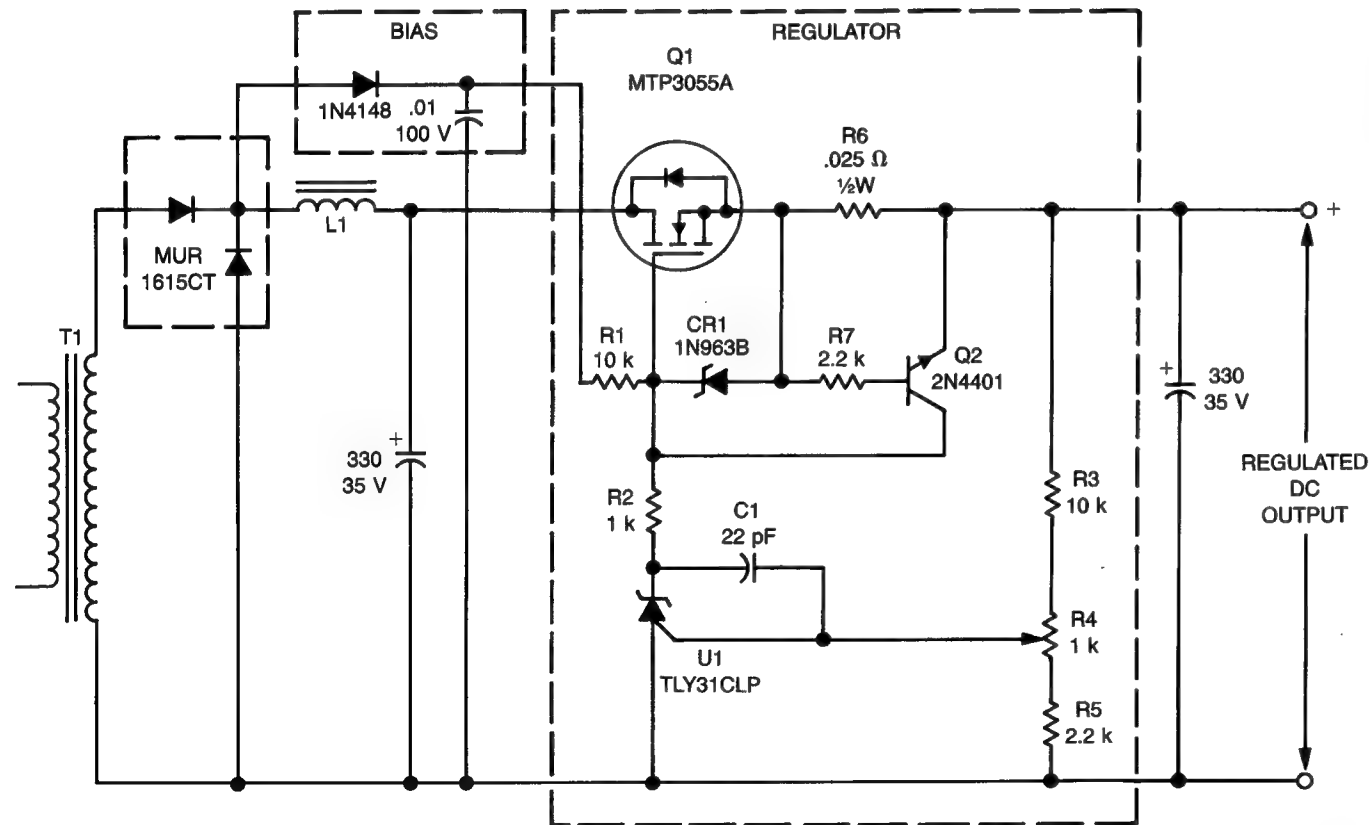
Linear power supplies are especially well-suited as post regulators in switcher designs. Performance of these linear supplies can be enhanced by using a power MOSFET series regulator, taking advantage of their very low dropout voltage and very low bias current requirements. Other factors, such as regulation, ripple rejection and transient response are equivalent to or better than the performance of conventional bipolar series pass transistors. In the circuit shown, circuit simplicity, small size and cost round out its features.

This linear post regulator provides 12 V at 3 A. It employs a TL431 reference (U1) which, without additional amplification, drives the gate of the TMOS MTP3055A (Q1) series pass regulator. Bias voltage is applied through R1 to Q1's gate, which is protected against overvoltage by diode CR1. Frequency compensation for closed loop stability is provided by C1.

Q1 was selected for a low $r_{DS(ON)}$ within the required voltage and current ratings. Any type of MOSFET can be chosen, but the best performance can be obtained from a device that is optimized for low ON resistance at low operating voltages. The TL431 shunt regulator, in a TO-92 package, is chosen for U1, considerably simplifying the design. R6, R7 and Q2 are optional; they can be added whenever peak current limiting is required.

Key performance features are:

Dropout voltage	0.6 V
Line regulation	± 5 mV
Load regulation	10 mV
Output ripple	10 mV pk-pk



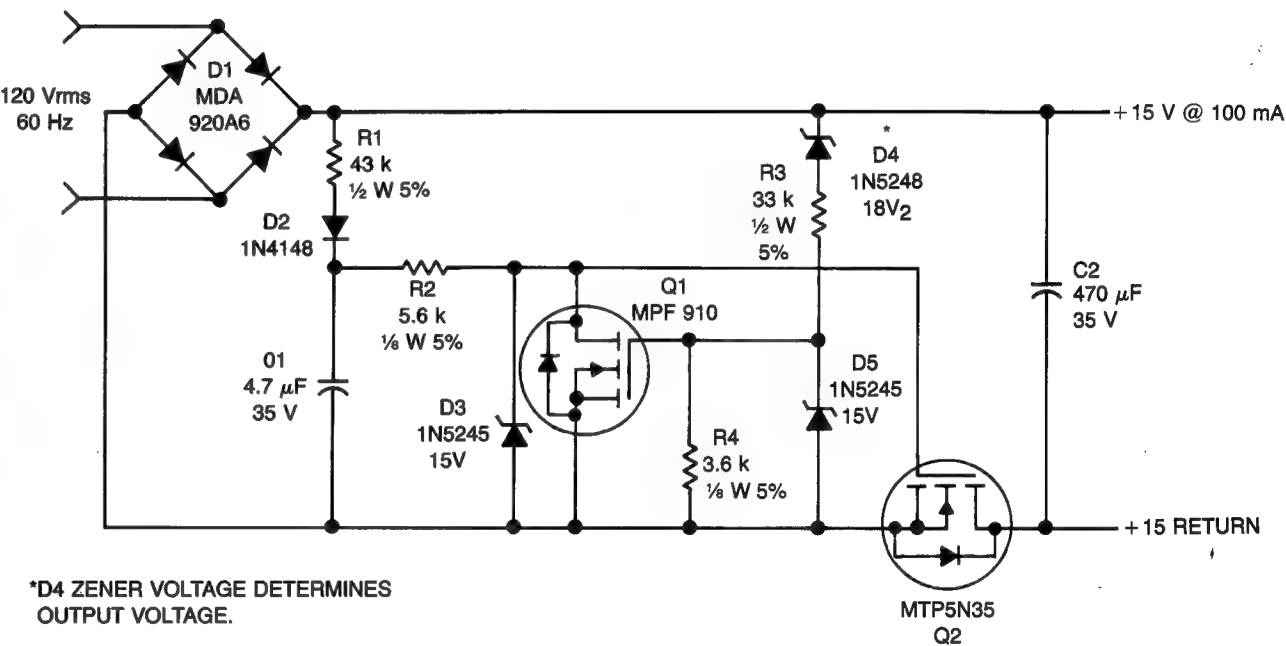
Power Sources

1.5 W Offline Converter
Woody Skelton, Boulder, CO

This non-isolated, unregulated, minimum component converter fills the void between low power zener regulation and the higher power use of a 60 Hz input transformer. It is intended for use where a non-isolated supply is safe. Commercial uses could include digital clocks and timers, NiCad battery chargers, and battery eliminators for small radios, calculators and toys. Industrial uses could include delay timers, digital indicators and low power controls with opto-isolated or relay outputs.

The circuit operates by conducting only during the low voltage portion of the rectified sine wave. R1 and D2 charge C1 to approximately 20 V, which is maintained by Q1. This voltage is applied to the gate of Q2, turning it ON. When the rectified output voltage exceeds the zener voltage of D4, Q1 turns ON, shunting the gate of Q2 to ground, turning it OFF.

MOSFETs allow this circuit to function with greater efficiency than bipolar transistors and permit a lower component count. The slow switching ramps of this circuit can best be handled by MOSFETs.



Power Sources

High Voltage Bucking Regulator

Jim Hagerman, Maynard, MA

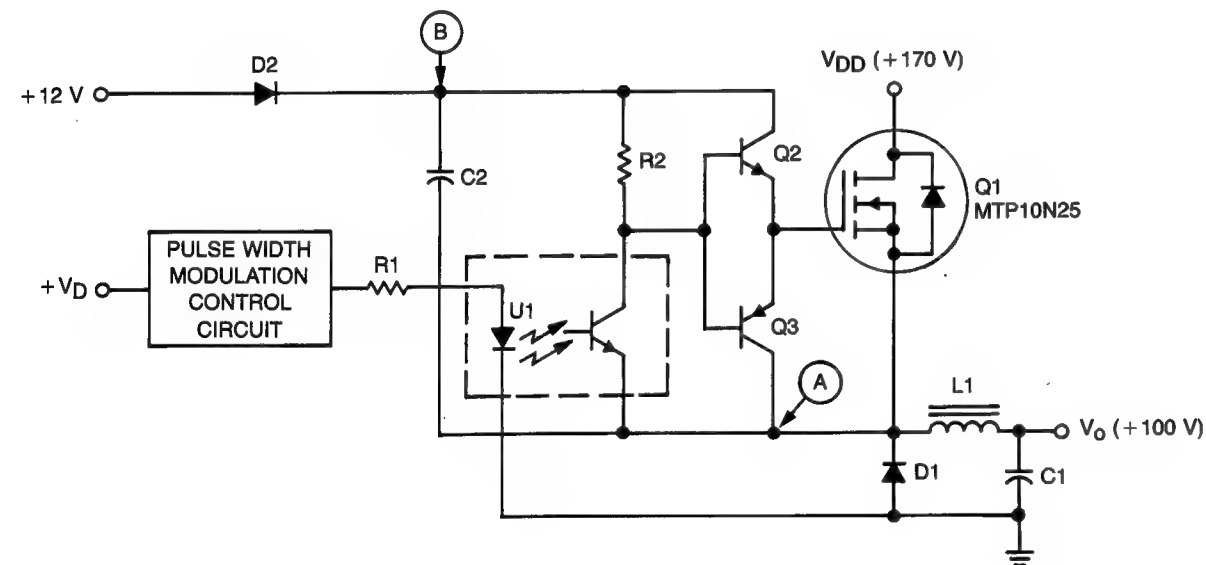
This circuit is basically the classic bucking regulator, except it uses a TMOS N-channel Power FET for the chopper and creates its own supply for the gate control.

The pulse width modulator can be just about any standard IC or circuit available for this purpose. Its output pulse drives the LED side (via a current limiting resistor) of opto-isolator U1. This isolation is necessary because the gate drive circuit power supply goes up and down with the voltage at point A.

The unique aspect of this circuit is how it generates a separate supply for the gate circuit, which must be greater than V_{DD} . When power is applied, C2 charges up, through D2, to +12 V. At this time, Q1 is OFF and the voltage at point A is just below zero. When the pulse modulated signal is applied, the opto-isolator transistor, Q2 and Q3 supply a signal to Q1 that turns it ON. The voltage at point A then goes to V_{DD} , C2 back-biases D2, and the voltage at point B goes to 12 V above V_{DD} .

After Q1 is turned ON, current starts to flow through L1 into C1, increasing until Q1 turns OFF. The current still wants to flow through L1, so the voltage at point A moves toward negative infinity, but is clamped by D1 to just below zero. Current flows less and less into C1 until Q1 turns ON again. Q2 and Q3 drive Q1's gate between the voltages at point A and B, which is always a 12 V swing, so $V_{GS \text{ max.}}$ is never exceeded.

For proper operation, the 12 V supply has to be established before the pulse width modulator signal is applied.



Power Sources

High Efficiency Flyback Voltage Converter

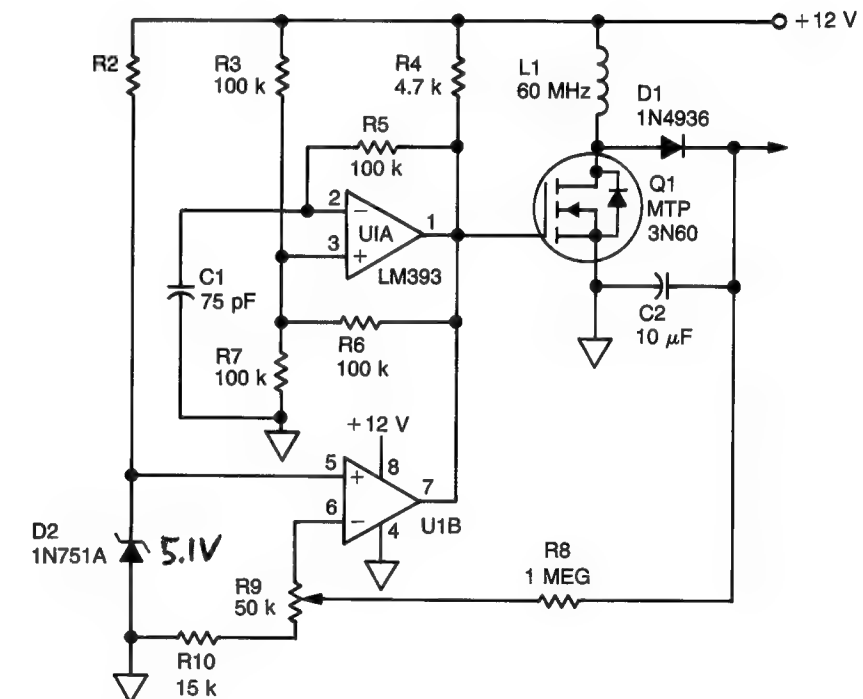
James Marshall, Dallas, TX

This flyback voltage converter provides a simple means for generating a regulated high voltage with few components and high efficiency. A great deal of circuit simplicity and efficiency is due to the use of a TMOS Power FET for Q1. Providing adequate drive current for a bipolar transistor would have required an additional stage with additional losses.

U1 is a dual voltage comparator with open collector outputs. The "A" side is an oscillator operating at 100 kHz and the "B" side is part of the regulation circuit that compares a fraction of the output voltage to a reference generated by zener diode D2.

The output of U1A is applied directly to the gate of Q1. During the positive half-cycle of the Q1 gate voltage, energy is stored in L1; in the negative half it is discharged into C2. A portion of the output voltage is fed back to U1B to provide regulation. The output voltage is adjustable by changing feedback potentiometer R9.

Component values shown produce a nominal 300 V output from a 12 V source. However, the circuit maximum output voltage is limited by R10; a lower value of R10 yields a higher output voltage. Output voltage is also limited by the breakdown values of Q1, L1, D1 and C2.



Power Sources

HV Regulator With Foldback Current Limiting

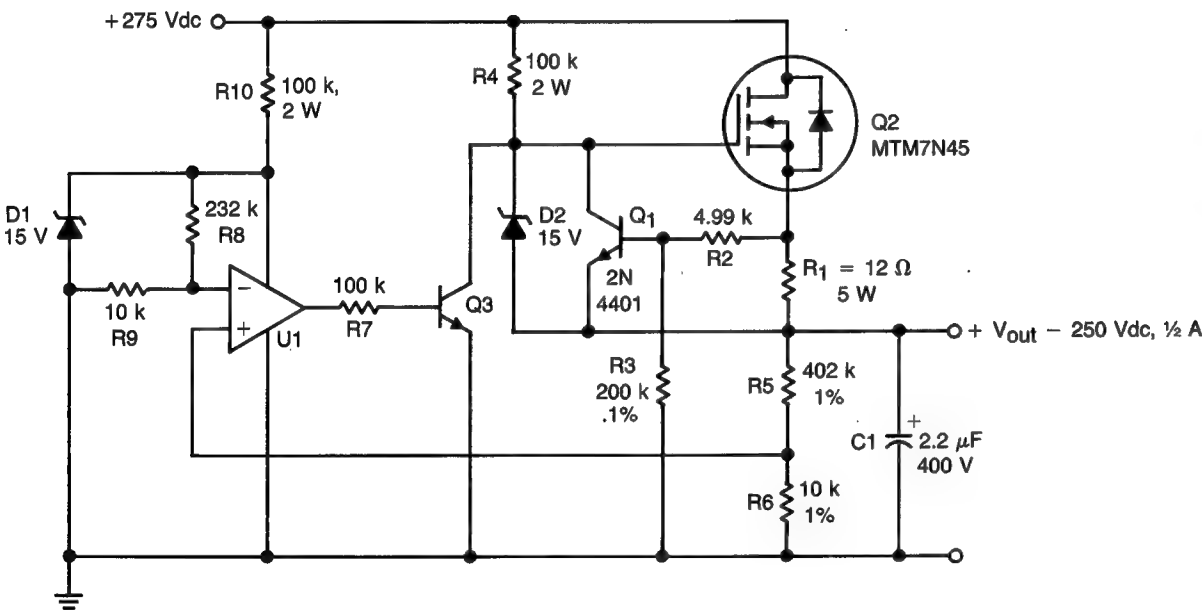
Larry Sears, Cleveland, OH

A TMOS MTM7N45 (Q2) is used as a series pass element in a linear high voltage supply that accepts +275 V unregulated and produces 250 V regulated with foldback current limiting.

A 15-V zener, D1, provides the dc reference for operational amplifier U1, whose other input is obtained from a fraction of the output voltage. U1 drives Q3, which drives the gate of Q2. Foldback current limiting is achieved by R1, R2, R3, R4, Q1 and D2. The formula to establish the current "knee" for limiting is:

I_{KNEE} = (V_{OUT}(R2/R2 + R3) + 0.5 V) / R1

Short circuit current is: I_{SC} = 0.5 V / R1



Power Sources

Uninterruptible Power Supply For Personal Computers

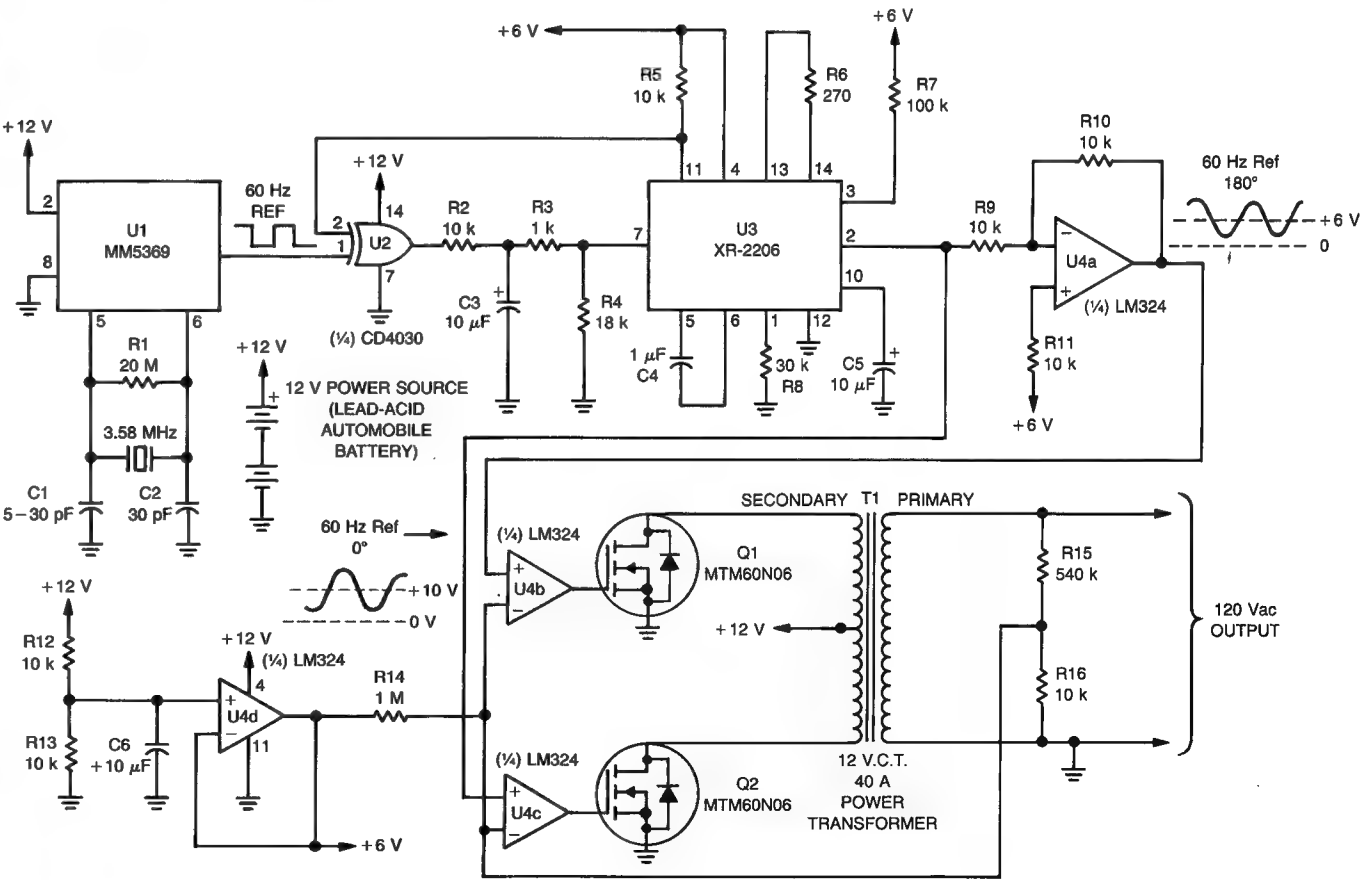
Bill Williams, Columbus, OH

A cost effective Uninterruptible Power System can be an important accessory for personal computers. Presented here is a low cost, stable, precisely 60 Hz, 120 VAC, 4 A UPS.

The UPS is basically an AC inverter that is powered by a 12 V, lead-acid automobile battery. During power outages, it can supply several minutes of power for an average personal computer. It incorporates a crystal-controlled 60 Hz time base, so that a computer with a real time clock can maintain its accuracy. It isolates the ac line from the computer, so it can be used to operate sensitive electronic equipment on noisy power sources.

Two MTM60N06 Power FETs (Q1 and Q2) alternately switch current through a center-tapped 120 V-to-12 V filament transformer (T1) with its primary and secondary reversed. The 120 V output is compared with a 60 Hz reference in a closed-loop configuration that maintains a constant output at optimum efficiency.

A 60 Hz reference frequency is derived from a crystal oscillator and divider circuit, U1. An inexpensive 3.58 MHz color burst crystal provides the time base that can be accurately adjusted by C1. The 60 Hz output from U1 is applied to the exclusive-OR gate, U2, and then to the XR-2206 function generator (U3) that converts the square wave into a sine wave. U2 and U3 form a phase-locked loop that synchronizes the sine wave output of U3 with the 60 Hz square wave reference of U1. The sine wave is then inverted by op amp U4a, so that two signals 180° out of phase can be applied to U4b and U4c that drive Q1 and Q2. Due to the closed-loop configuration of the drive circuits, Q1 and Q2 conduct only during the upper half of the sine wave. Therefore, one TMOS device conducts during the first half of the sine wave and the other conducts during the second half.



High Efficiency, 80-Meter Amateur Radio Transmitter

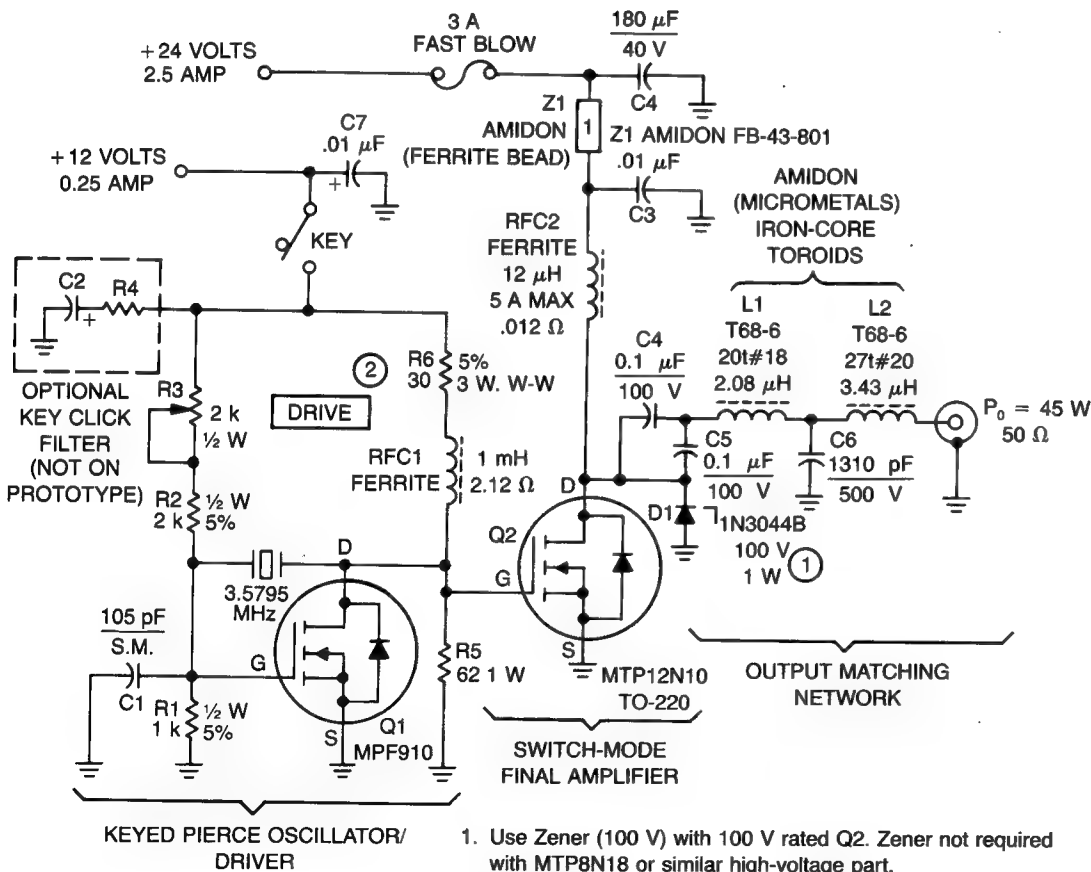
Robert G. Culter, Beaverton, OR Second Prize Winner

This transmitter consists of a keyed crystal oscillator/driver and a high efficiency final, each with a TMOS Power FET as the active element. Total parts costs are less than \$20 and no special construction skills or circuit boards are required.

The Pierce oscillator is unique because the high C_{iss} of the final amplifier Power FET (700-1200 pF) is used as part of the capacitive feedback network. In fact, the oscillator will not work without Q2 installed. The MPF910 is a good choice for this oscillator because it is capable of driving the final amplifier in a switching mode while still retaining enough gain for oscillation.

To minimize cost, a readily-available color burst TV crystal is used as the frequency determining element for Q1.

An unusual 84% output efficiency is possible with this transmitter. Such high efficiency is achieved due to the TMOS Power FET's characteristics along with modification of the usual algorithm for determining output matching. Drain impedance is assumed to be: $R_o = (V_{cc})^2 / 2 \cdot P_o = (24)^2 / 2 \cdot 50 = 5.76 \Omega$. We can assume the drain resistance is a factor of two higher due to conduction being cut off for a larger part of the cycle. Therefore, the matching network can be calculated for the case where the drain voltage is allowed to exceed V_{cc} by a considerable amount for part of the conduction cycle. The resulting efficiency exceeds the usually expected 50% from Class C operation.



1. Use Zener (100 V) with 100 V rated Q2. Zener not required with MTP8N18 or similar high-voltage part.
2. Adjust DRIVE for minimum oscillation delay on keying.

Double Sideband, Suppressed Carrier R.F. Modulator

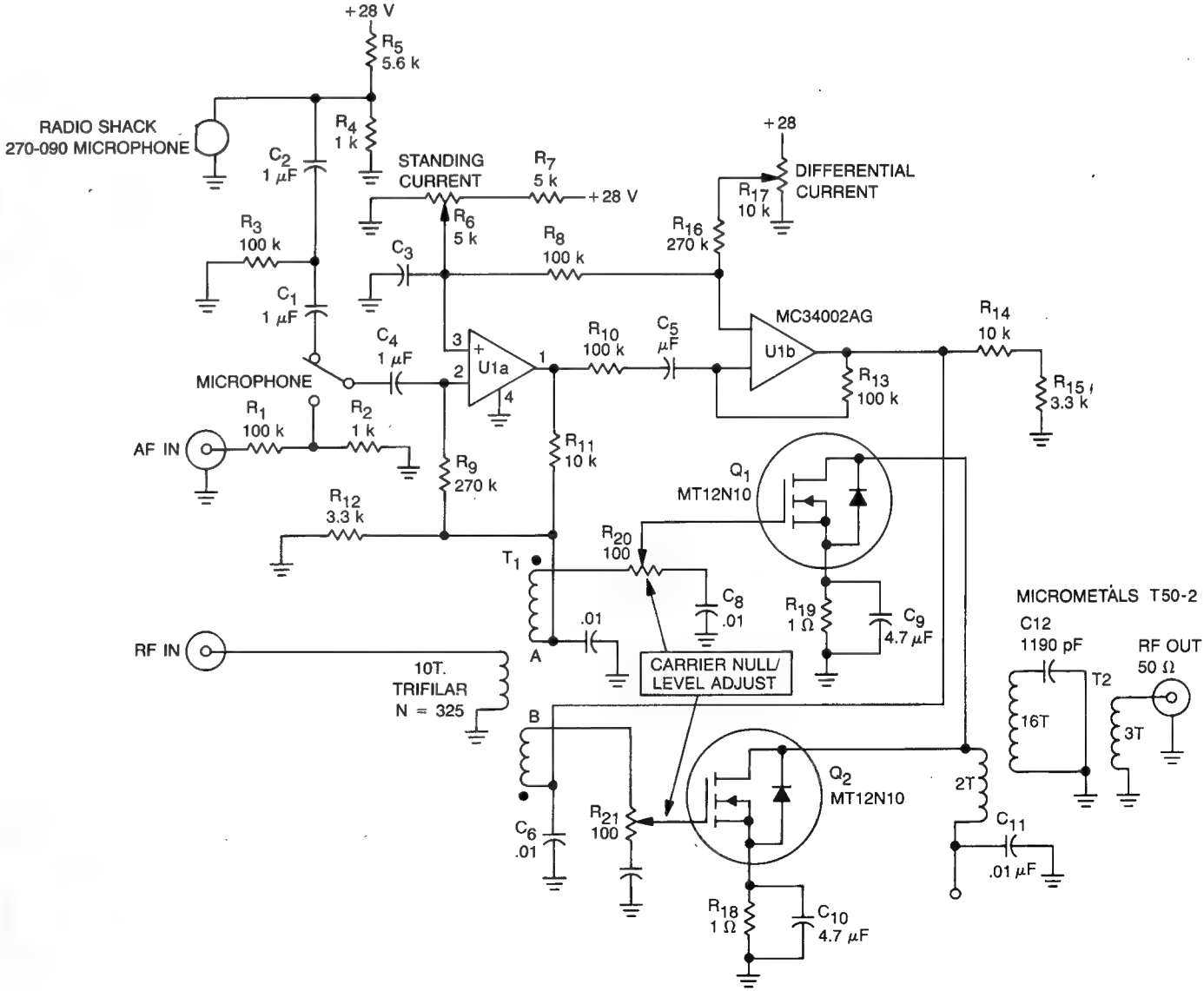
Larry Lockwood, McMinnville, OR Third Prize Winner

High power gain at both AF and RF frequencies are possible with TMOS Power FETs. In particular, RF applications can take advantage of the large SOA, which minimizes the concern for the harmful effects of reflected energy on the output devices. Furthermore, the linearity of Power FETs improves the modulation process.

An RF input is applied to the primary of T1, which applies equal amplitude, opposite phase RF drive for output FETs Q1 and Q2. With no AF modulation at points A and B, the opposite phase RF signals cancel each other and no output appears at the 50v output connector.

When AF modulation is applied to points A and B, a modulated RF output is obtained. DC stability and low frequency gain are improved by source resistors R18 and R19.

A phase inverter consisting of a dual op amp (U1a and U1b) produces the out-of-phase, equal amplitude AF modulation signals.



Low Distortion, High Power AM Transmitter Modulator

Fred Studenberg, Melbourne, FL

To meet worldwide regulations, transmitter modulation distortion must be less than 1% of the 80% modulation level. Therefore, it was decided to improve the existing modulator design to provide more margin for this adjacent channel power specification.

The original bipolar transistor design produced 2 V at an 8% duty cycle. Modulation below 2 V caused the modulator to be completely cut off for a number of cycles, which produced high order harmonics at the modulation valleys. The result was adjacent channel noise.

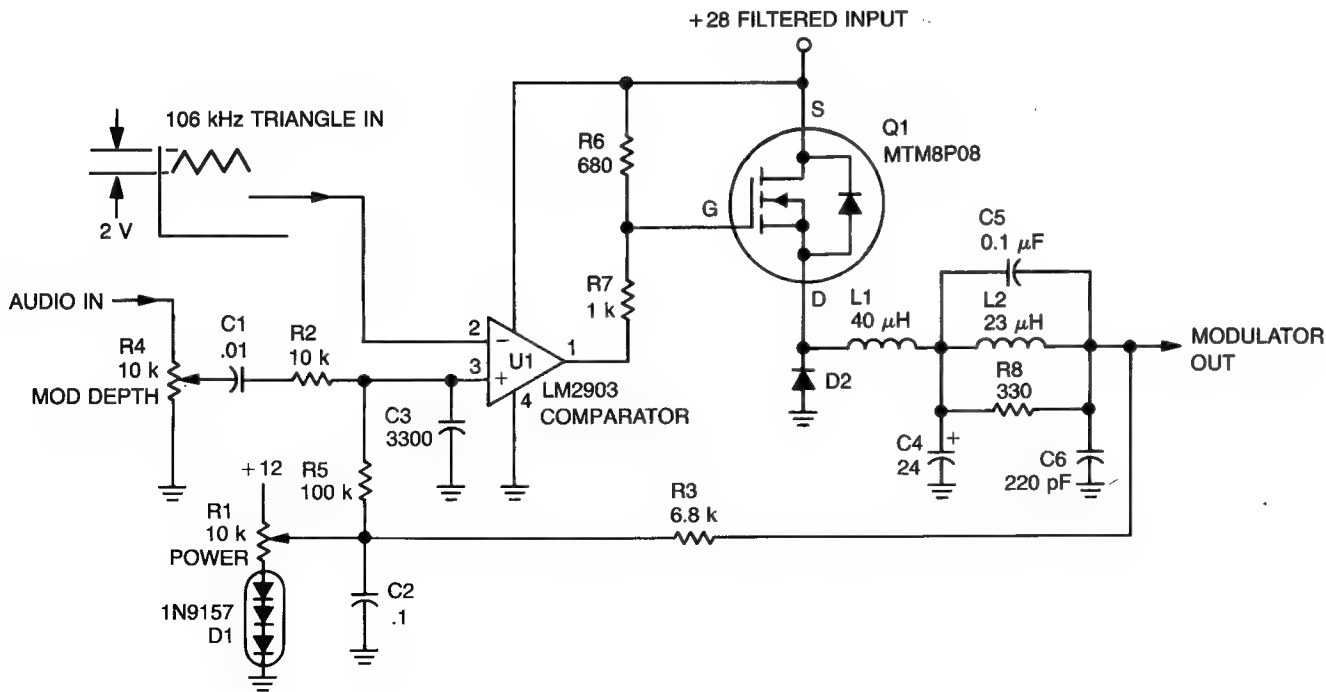
In the new circuit shown here, normal drain voltage is set at 12 V and is modulated from (ideally) 0 to 24 V for 100% amplitude modulation. Modulator requirements are approximately 5 A at the 12 V carrier level, rising to 10 A at modulation peaks of 24 V.

A single MTP8P10 performs the main switching function. With storage time eliminated from the switch, distortion caused by the modulator is eliminated and the predominant distortion of the transmitter is set by the modulated Class C stages. Furthermore, overall efficiency is improved by faster switching frequencies.

In operation, a 106 kHz triangular wave with a peak-to-peak amplitude of V_p is applied to the LM2903 comparator (U1). For any portion of the cycle in which V_p is greater than the reference input (pin 3 of U1), Q1 drain becomes 28 V minus the voltage drop due to R_{ds} . Thus, the output at the Q1 drain = $28(1 - E_{REF}/V_p)$, where E_{REF} is the reference voltage.

The variable cycle square wave output from the drain is applied to the low pass filter formed by L1, C4 and C6. This provides a near dc output with the L2-C5 resonant trap filtering the fundamental switching frequency. Diode D2 permits current in the low pass filter when Q1 is in OFF (energy stored in L1 and L2 is released).

E_{REF} is derived from three sources. First, the dc level set by R4. Second, the 300-3000 Hz modulating frequency that shifts the reference at the modulating rate. Third, the dc feedback primarily controlled by R5. Capacitor C3 determines the closed loop cutoff frequency; it was chosen to compensate for the large phase shift introduced by the low pass filter.

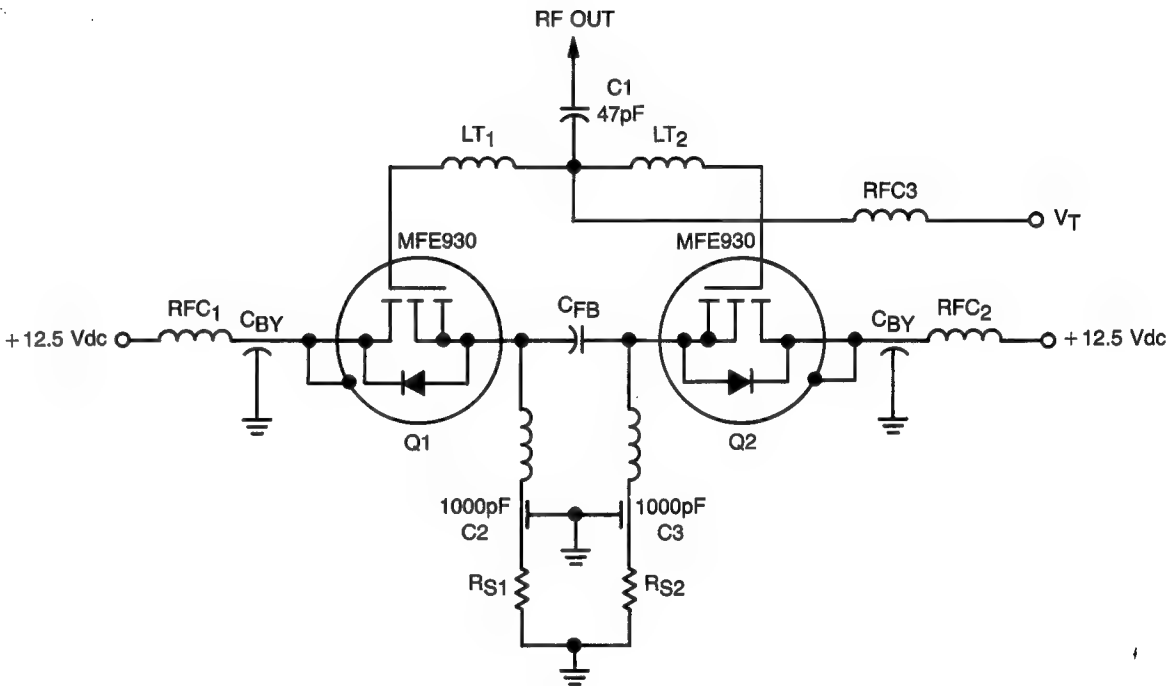


Balanced TMOS VCO

John Jones, Dayton, OH

This TMOS VCO operates in push-pull to produce 4 W at 70 MHz. It consists of two MFE930 TMOS devices in a balanced VCO that generally provides better linearity than that of single-ended types. Varactors are not used because the design takes advantage of the large change in "Miller" capacitance, C_{rss} , that is available in TMOS gate structures.

In the balanced VCO, the fundamental (f_o) and/or twice the fundamental ($2f_o$) can be coupled from the circuit at separate nodes. This makes the balanced oscillator very useful in phase-locked loops. The fundamental, $f_o = \frac{1}{2\pi} (L_t C_{rss})^{-1/2}$, where $L_t \approx 0.68 \mu H$.



RF Power Switch

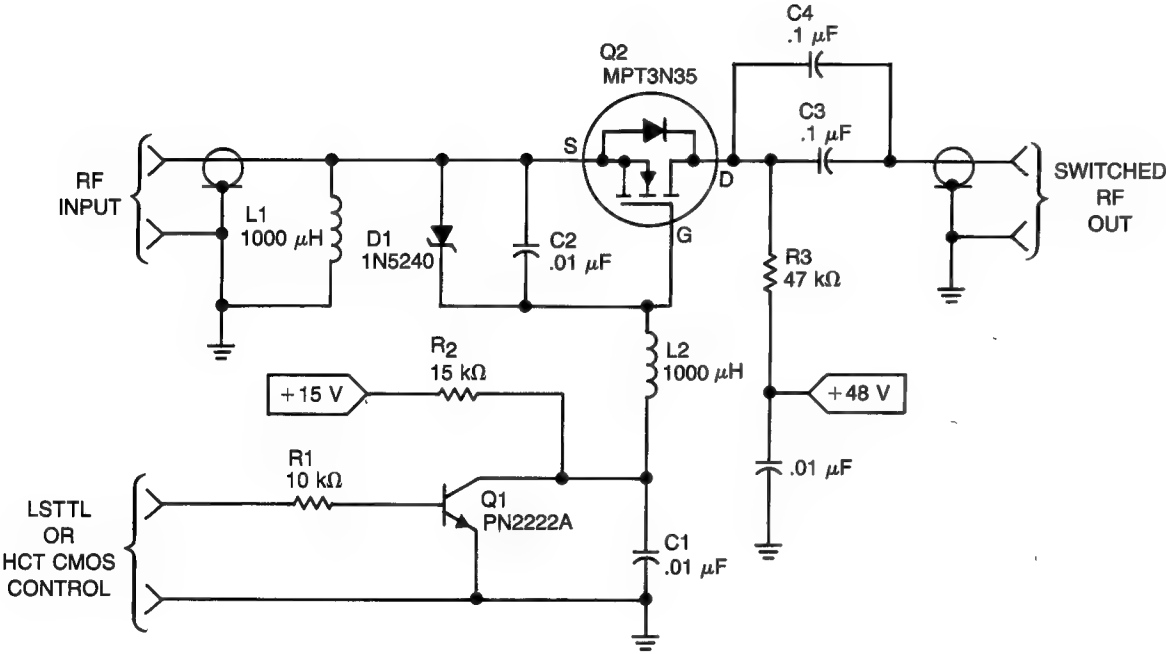
Robert Rouquette, Harahan, LA

PIN diodes have served well in RF power switching applications, but a TMOS Power FET provides acceptable performance with simpler drive requirements. The TMOS version lowers the overall cost and space requirements, when power supplies are included in the analysis. The Power FET does not need a heat sink other than the pc board, in this application.

A low current, high voltage supply is common to both the PIN and Power FET designs. The supply reverse biases the PIN diodes or the Power FET intrinsic diode

in the OFF state. In the On state, a PIN diode switch requires 150 mA forward bias from a +5 V supply. The Power FET requires 1 mA from a +15 V supply in the ON state.

This RF power switch operates at 1.7 MHz with a 50v source and load. Its ON loss is 0.2 dB and its OFF isolation is 30 dB. It provides 40 W PEP, 45 V_{peak} and 0.9 A_{peak}. The control input can come from CMOS, TTL, LS, etc. to turn ON Q1, which turns ON Q2, a TMOS MTP3N35.



μP-Controlled Servo Amplifier With TMOS-Darlington Output

Ned Dammeyer, New Bremen, OH

The following requirements were established for a pulse width modulated (PWM) motor drive servo amplifier:

- 1. 24 V battery operation
- 2. <5 mA standby current
- 3. Survive a locked-rotor
- 4. Survive a shorted output
- 5. All positioning requires an initial full-on (acceleration)
- 6. Position loop closed through the μP
- 7. All safety circuits in hardware to meet the speed requirements to shut down rather than process an interrupt

The output stage is an "H" bridge consisting of two TIP140T NPN Darlington emitter followers (Q2 and Q7) and two MTP3055A TMOS Power FETs (Q4 and Q5). Q1 and Q8 PNP pre-drivers act as direction switches to supply the necessary current to source Q2 and Q7. PNP drivers Q3 and Q6 provide low impedance sourcing to turn on Q4 and Q5.

Two inputs are required from the μP: a direction command determined by the polarity between the command and feedback signals, a speed pulse determined by the magnitude of the error signal. In addition, a third signal from the servo amplifier notifies the μP of an over-current fault.

The position input is clocked into the U1a "D" latch on the leading edge of the first speed pulse following a direction change. Inputs A and B, applied to U5 (4-bit AND/OR Selector), select the inputs to be connected to

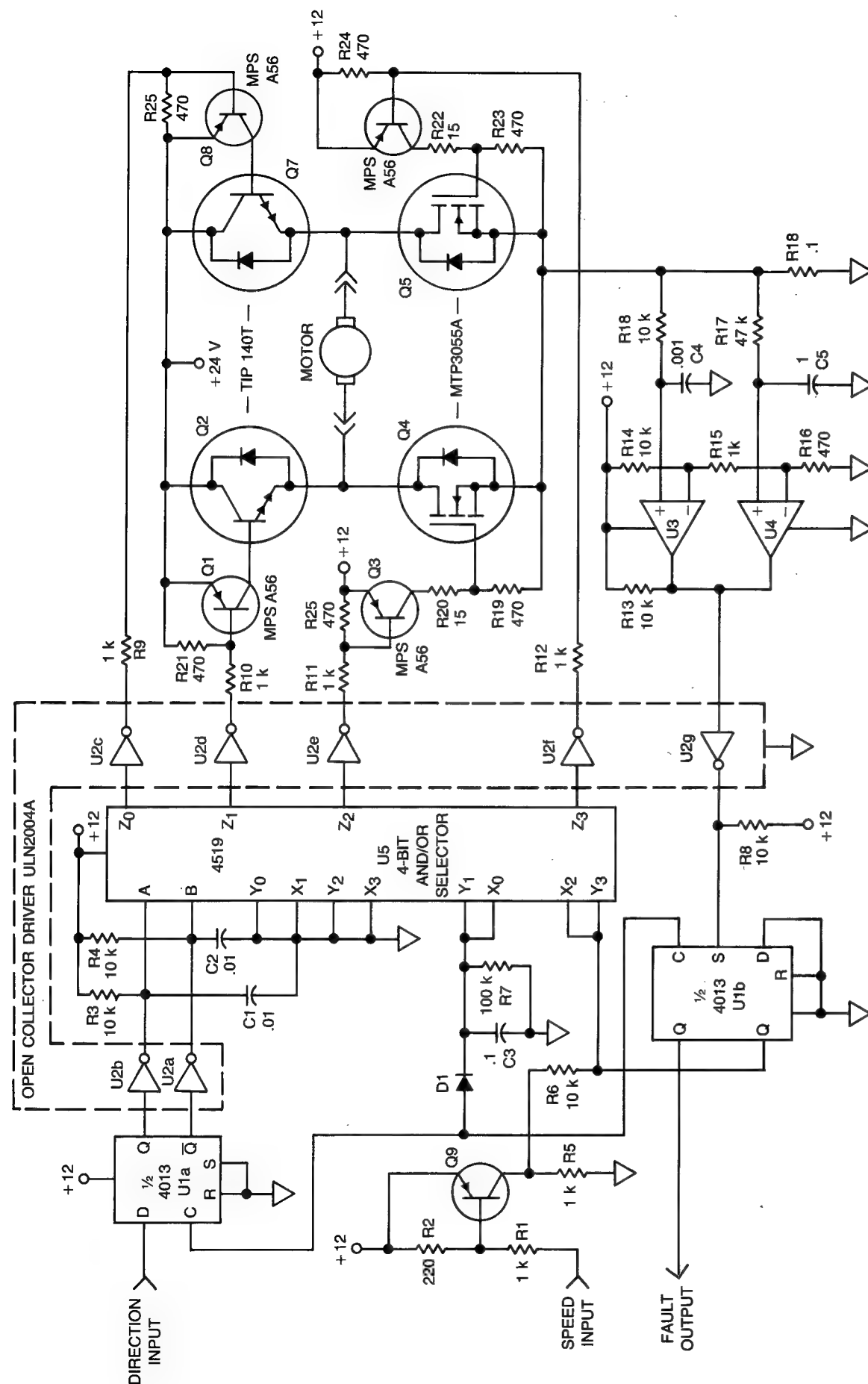
the outputs. These inputs are derived from U1a via inverters U2a and U2b and R-C time constants consisting of R3-C1 and R4-C2. The time constants prohibit the possibility of both legs of the "H" bridge conducting simultaneously. This induces a lag on the initiation, or rising edge, of the direction that is selected.

Speed input is a 1 kHz, variable pulse width signal that is switched by driver transistor Q9 to inputs Y1, X0, X2 and Y3 of U5. If the direction input causes U5's A input to go high, all the "X" inputs to U5 are selected, and the following occurs:

- 1. Z0 output goes high, turning ON Q7
- 2. Z1 output goes low, disabling Q2
- 3. Z2 output is pulsed, driving Q4 at a variable pulse width
- 4. Z3 output goes low, disabling Q5

When this happens, the motor turns in the direction that nulls the position loop error. When there is no longer an error (no pulse width), the integrated inputs to U5's X0 and Y1 decay to zero, even though a direction is selected by U1a. If the B input to U5 is selected to go high, the opposite devices of the "H" bridge conduct and drive the motor in the opposite direction.

Comparator U4 provides current limiting in case of a locked rotor or over 20 msec acceleration time. Current limiting is also initiated if U3 catches the higher amplitude and fast transitions that occur if a system is miswired, or the output is shorted. In addition, a "Fault" signal is sent to U1b, which sends this information to the μP.



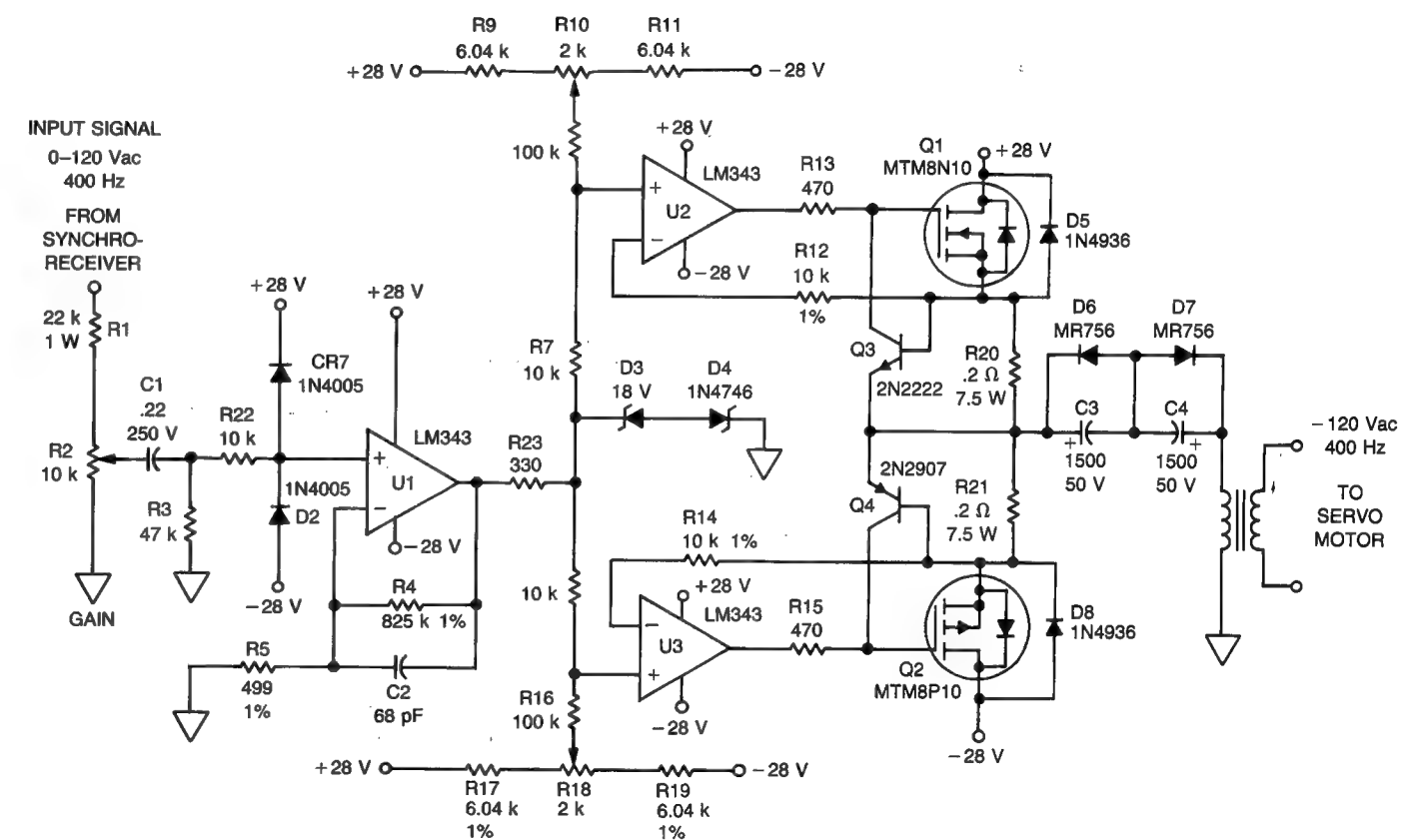
Servo Amplifiers

400-HZ Servo Amplifier

Larry Ducas, Industry, CA

In this 400-Hz servo amplifier, full advantage is taken of the low power drive requirements for TMOS devices. Operational amplifiers provide direct drive for the TMOS output Power FETs, which in turn drive the servo motor through a step-up transformer...no power driver circuits are needed. Another TMOS advantage is freedom from second breakdown, which can occur in bipolar devices.

The signal from a synchro receiver or a variable resistive cam follower (potentiometer) is boosted by operational amplifier U1, whose output swing is limited by back-to-back zeners D3 and D4. The signal is then applied to operational amplifiers U2 and U3, which drive the gates of Q1 and Q2, respectively. NPN transistor (Q3) is a fast current limiter for the N-channel MTM8N10; a PNP transistor (Q4) performs the same function for the P-channel MTM8P10. Capacitors C3 and C4 eliminate the need for accurate dc offset zeroing. T1 steps up the output voltage to 120 V for the 400 Hz servo motor.



Servo Amplifiers

Maximum Efficiency H Bridge Power Amplifier

Lealon R. McKenzie, Tulsa, OK

Today, many servo motor designs must meet international safety regulations, such as TUL/VDE shock hazards, which require secondary power supplies below 42.4 V. To meet these specifications and minimize current, the motor torque/voltage constants must be chosen for a maximum RPM load with the full secondary output of 40 V. Use of the full secondary output voltage dictates an "H" bridge power amplifier instead of a split secondary (± 20 V) supply.

A number of "H" bridge configurations can be used, but the single side switching technique shown here has been found to be particularly effective. Referring to the figure, this bridge technique offers reduced C1 RMS and peak-to-peak current and the C1 effective series resistance (ESR) is removed from the L/R discharge path. Furthermore, switches Q2 and Q4 can be chosen with a lower ON resistance than Q1 and Q3, which improves efficiency twofold by increasing the percentage of time Q2 and Q4 conduct due to the L/R discharge time constant.

The next step is to choose the power switch. Fast switching speeds, large SOA, bidirectional current current carrying capacity, and the ability to select ON resistance as a function of cost makes TMOS the obvious and only choice. If the design operates just below the TUL/VDE safety extra low voltage (SELV) for maximum efficiency, use of P-channel FETs for Q1 and Q2 is required. P-channels are chosen because N-channel FETs need a gate voltage of 12 V with respect to the source in order to saturate. Therefore, to saturate and get a 40 V source voltage requires the gate voltage to be 40 + 12, or 52 V; that is over the SELV.

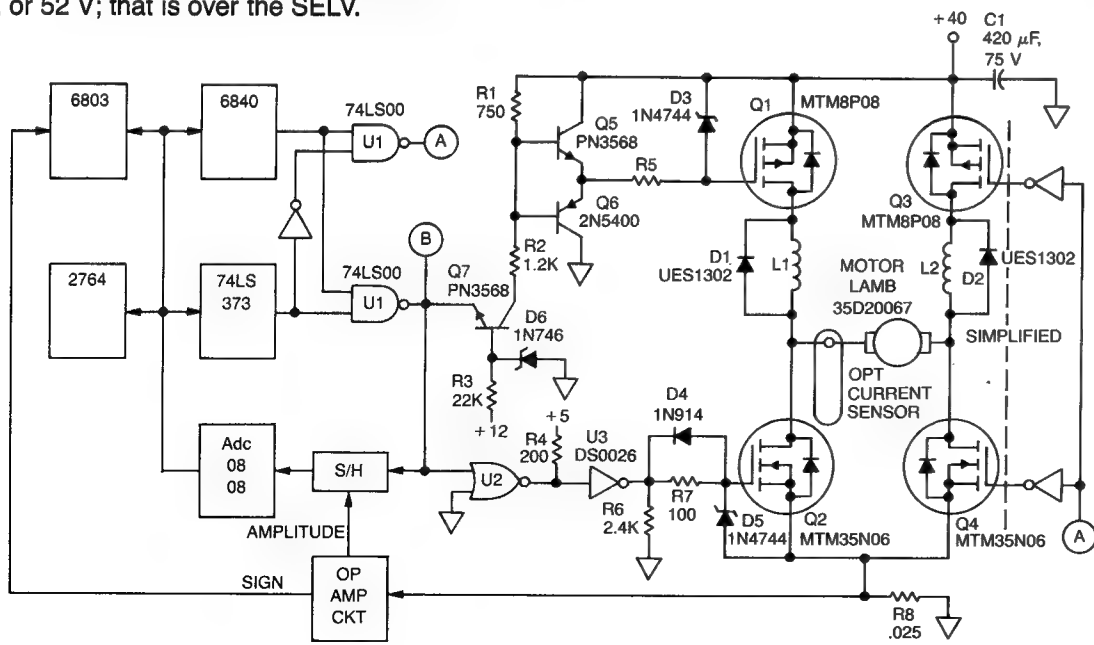
Specifications for the amplifier are:

C1 ESR	0.1
Q1 and Q3 $r_{DS(ON)}$	0.4
Q2 and Q4 $r_{DS(ON)}$	0.28
Motor resistance	0.5
Motor inductance	2.5 mH
Motor KT	54 oz-in./A
Motor load profile	540 oz-in. accelerated from 0 to 250 RPM
Servo control	Current-controlled minor loop

In the circuit shown, drive circuits for Q3 and Q4 are shown simplified; they originate at point A and are identical to the drive circuits that originate at point B and are applied to Q1 and Q2.

Based on the required motor current, the 6803 microprocessor generates a pulse width modulated signal and applies it to U1 via the 6840 timer. Direction information is produced by the 74LS373; if the direction is high, point A goes high and U1 pulses Q7 low. This causes Q7 to turn ON, dropping the base and emitter voltages of Q5 and Q6 from 40 to approximately 28 V. Q1's gate is -12 V with respect to its source, so it turns ON. At the same time, the low pulse from U1, amplified by U2 and U3, drops Q2's gate from +12 V to 0 V, turning Q2 OFF.

The motor inductance is charged by current from C1 through Q1, L1, Q4 and R8. L1 and L2 provide the switching current limit protection needed for synchronous rectification.



Servo Amplifiers

DC Servo Drive Employs Bipolar Control Input

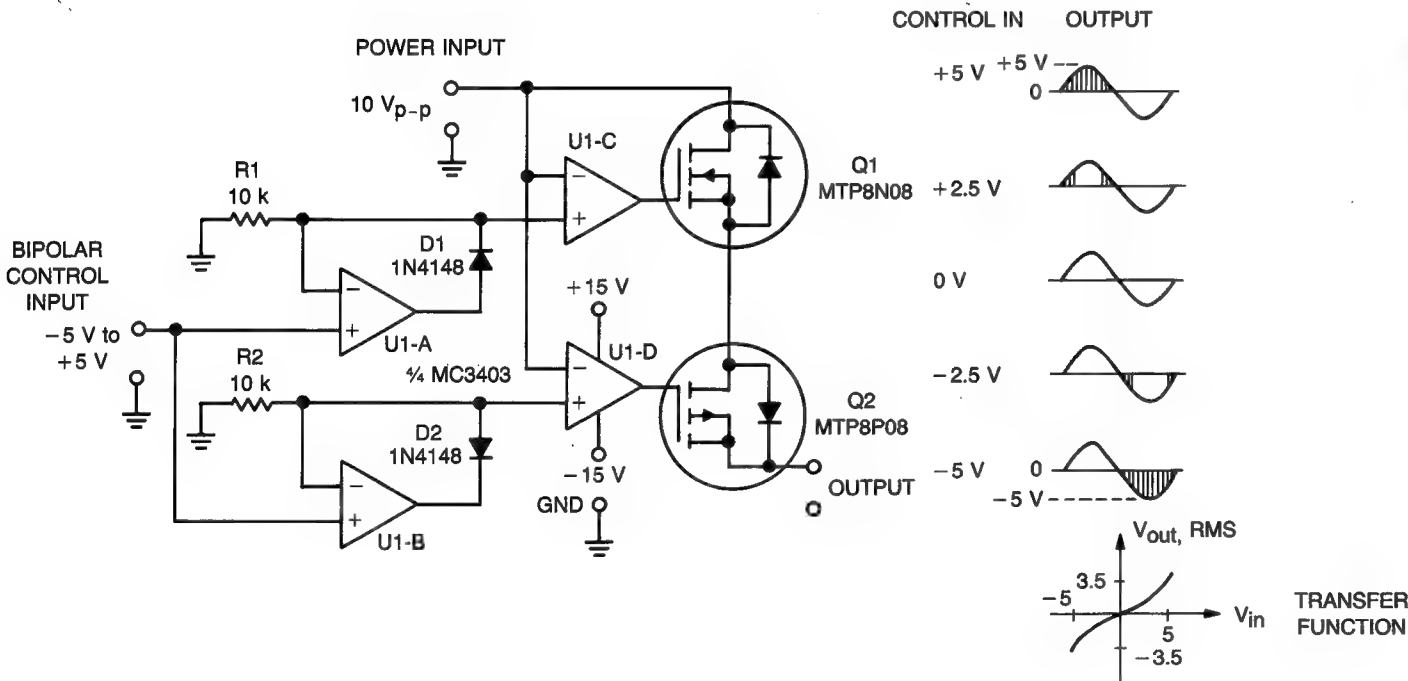
Davide Andrea, Boulder, CO

This circuit accepts bipolar control inputs of ± 5 V and provides a phase-chopped output to a dc load (such as a servo motor) of the same polarity as the input. The RMS voltage of the output is closely proportional to the control input voltage.

N-channel and P-channel TMOS devices, Q1 and Q2, are connected in anti-series to form a bidirectional switch through which current can flow in either the forward or reverse direction. Control circuits turn Q1 and Q2 ON when they are reverse biased, bypassing their reverse rectifier and increasing circuit efficiency. Each device is allowed to turn OFF only when forward biased.

The Q1-Q2 switch connects the ac power source to the load when its instantaneous voltage is the same polarity and less than the control voltage. U1a is configured as an ideal positive rectifier whose output follows the control voltage when it is positive, and is zero otherwise. Similarly, U1b is a negative rectifier. U1c turns Q1 ON whenever the ac input voltage is lower than the positive rectifier output. For negative control voltages, Q1 is turned ON only during the negative half-cycle. For positive control voltages, Q1 is turned ON during the end portions of the positive half-cycle. Similarly, U1d turns Q2 ON whenever the ac input voltage is higher than the output of the negative rectifier.

Operating voltages were selected to drive the TMOS devices for best conductance and to avoid exceeding the maximum TMOS gate voltage ratings and the operational amplifier supply. With the selection of a few components, operation at the maximum drain-source voltage is possible.



Servo Amplifiers

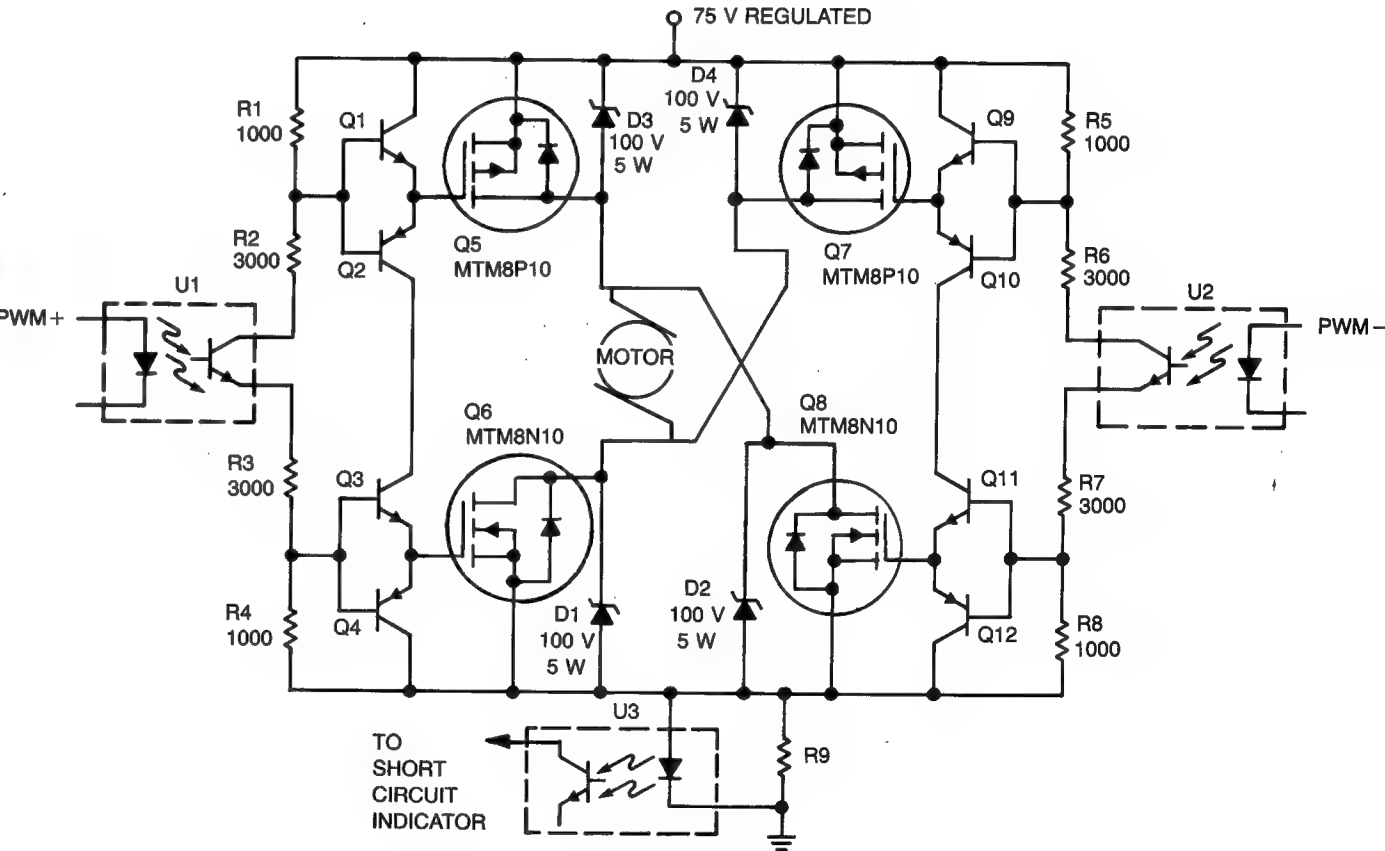
Servo Motor Drive Amplifier

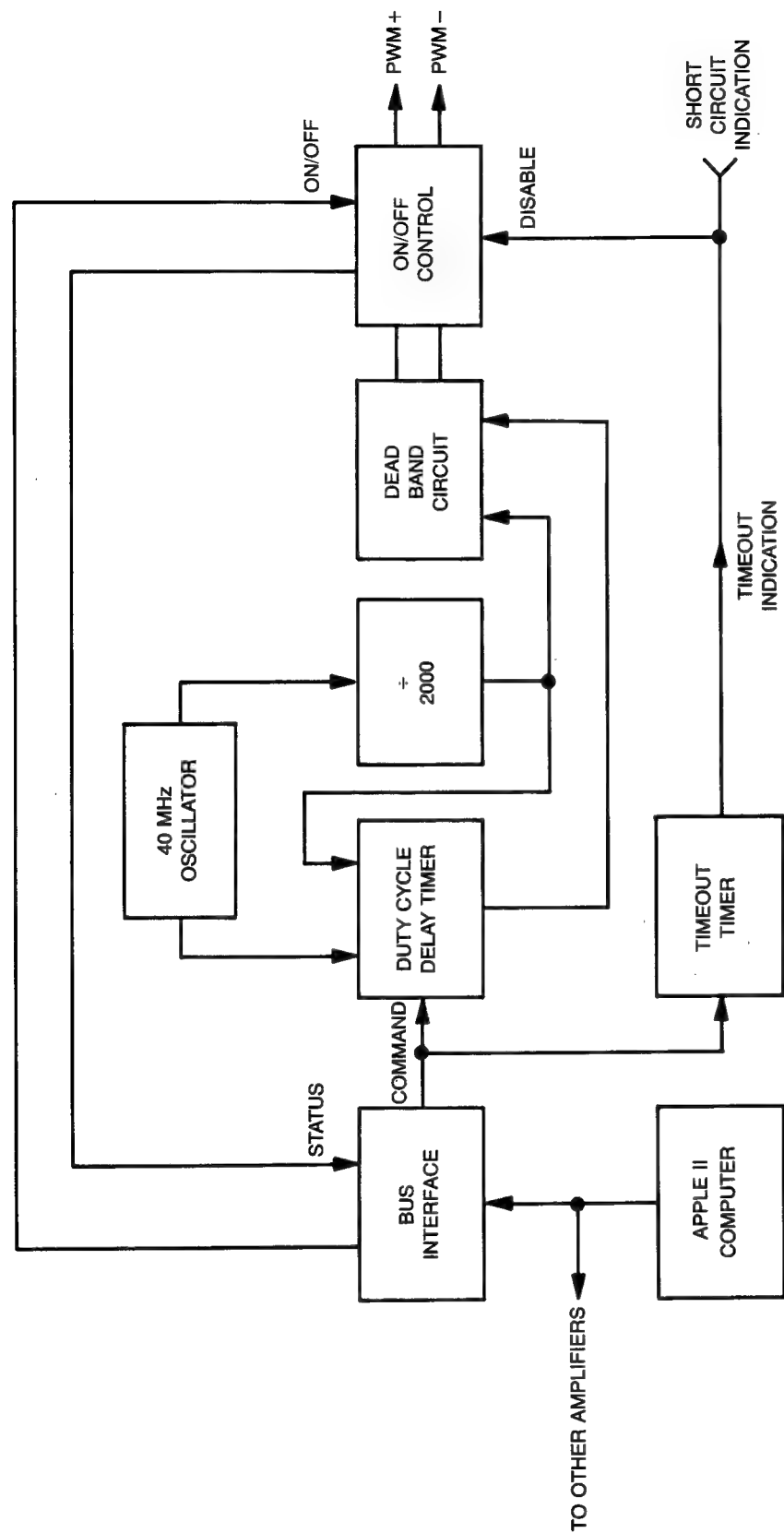
S.M. Killough, Oak Ridge, TN

Digital ICs and opto-isolators provide the drive for this TMOS servo amplifier, resulting in fewer analog circuits and less drift. Fast and consistent turn-on and turn-off characteristics also enable accurate analog output results directly from the digital signal without the need for analog feedback.

The resulting 12-bit resolution amplifier, designed for Apple II™ systems, can be chained with up to eight more amplifiers and still only require connection to one Apple II card slot. The mostly digital amplifier is easy to build and troubleshoot, resulting in a more economical, simpler and reliable high performance amplifier.

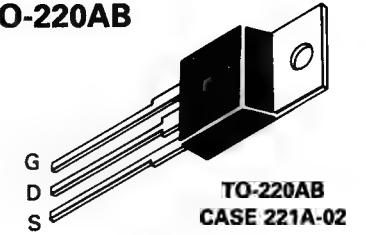
An "H" bridge configuration is employed for the servo amplifier, which obtains complementary PWM inputs from digital control circuits. The PWM inputs are applied via opto-isolators, which keep the digital control logic isolated from the 75 V supply used for the amplifier. A short circuit indicator is provided by opto-isolator U3; if there is a short, the drop across R9 increases to a value sufficient to activate the isolator and send a short indication to the digital control logic.





TMOS Selector Guides

Table 1 — Plastic TMOS Power MOSFETs — TO-220AB



V _{BR} (DSS) (Volts) Min	r _{DS(on)} @ I _D (Ohms) Max	I _D (Amp)	Device	I _D (Cont) (Amp) Max	P _D @ T _C = 25°C (Watts) Max
1000	10	0.5	MTP1N100	1	75
	7	1.5	MTP3N100	3	
950	10	0.5	MTP1N95	1	
	7	1.5	MTP3N95	3	
900	8	1	MTP2N90	2	125
	5	2	MTP4N90	4	
850	8	1	MTP2N85	2	75
	5	2	MTP4N85	4	125
800	7	1.5	MTP3N80	3	75
750			MTP3N75		
600	12	0.5	MTP1N60	1	
	6	1	MTP2N60	2	
	2.5	1.5	MTP3N60	3	125
	1.2	3	MTP6N60	6	
550	12	0.5	MTP1N55	1	75
	6	1	MTP2N55	2	125
	2.5	1.5	MTP3N55	3	
	1.2	3	MTP6N55	6	
500	8	0.5	MTP1N50	1	50
	6	1	MTP2P50*	2	75
	4		MTP2N50		
			IRF822		40
	3	1.5	IRF820	2.5	75
			MTP3N50	3	
	2		IRF832	4	
	1.5		IRF830	4.5	
			MTP4N50	4	125
	1.1	4	IRF842	7	
	0.85		IRF840	8	
	0.80		MTP8N50		
450	8	0.5	MTP1N45	1	50
	6	1	MTP2P45*	2	75
	4		MTP2N45		
			IRF823		40
	3		IRF821	2.5	
		1.5	MTP3N45	3	75
	2	2.5	IRF833	4	
	1.5	2	MTP4N45		
		2.5	IRF831	4.5	
	1.1	4	IRF843	7	125
	0.85		IRF841	8	
	0.8		MTP8N45		

*Indicates P-Channel

Table 1 — Plastic TMOS Power MOSFETs — TO-220AB (continued)
CASE 221A-02

V _{BR(DSS)} (Volts) Min	r _{DS(on)} @ I _D (Ohms) (Amp) Max		Device	I _{D(Cont)} (Amp) Max	P _D @ T _C = 25°C (Watts) Max
400	5	0.8	IRF712	1.3	20
		1	MTP2N40	2	50
	3.6	0.8	IRF710	1.5	20
	3.3	1.5	MTP3N40	3	75
	2.5		IRF722	2.5	40
	1.8		IRF720	3	75
	1.5	2	MTP4N40	4	
		3	IRF732	4.5	
	1	2.5	IRF730	5	125
	0.8		MTP5N40		
	0.55	5	IRF742	8	
			MTP10N40	10	
			IRF740		
350	5	1	MTP2N35	2	50
		0.8	IRF713	1.3	20
	3.6	1.5	IRF711	1.5	75
	3.3		MTP3N35	3	
	2.5		IRF723	2.5	
	1.8	2	IRF721	3	75
			MTP4N35	4	
	1.5	3	IRF733	4.5	
		2.5	IRF731	5.5	
	1		MTP5N35	5	125
	0.8	5	IRF743	8	
			IRF741	10	
			MTP10N35		
250	2	1	MTP2N25	2	50
	0.45	5	MTP10N25	10	100
200	2.4	1.25	IRF612	2	20
	1.8	1	MTP2N20		50
	1.5	1.25	IRF610	2.5	20
	1.2	2	MTP4N20	4	50
		2.5	IRF622	5	40
	MTP5N20		75		
	MTP5P20*		40		
	0.8	IRF620			
	0.7	3.5	MTP7N20	7	75
	0.6	5	IRF632	8	100
			IRF630	9	
	0.4	4	MTP8N20	8	
	0.35	6	MTP12N20	12	100
	0.22	10	IRF642	16	125
			IRF640	18	
180	1.8	1	MTP2N18	2	50
	1.2	2	MTP4N18	4	75
	1	2.5	MTP5N18	5	
			MTP5P18*		
	0.7	3.5	MTP7N18	7	100
	0.4	4	MTP8N18	8	
	0.35	6	MTP12N18	12	

*Indicates P-Channel

Table 1 — Plastic TMOS Power MOSFETs — TO-220AB
CASE 221A-02

V _{BR(DSS)} (Volts) Min	r _{DS(on)} @ I _D (Ohms) (Amp) Max		Device	I _{D(Cont)} (Amp) Max	P _D @ T _C = 25°C (Watts) Max	
150	2.4	1.25	IRF613	2	20	
	1.5		IRF611	2.5		
	1.3	1.5	MTP3N15	3	50	
	1.2		IRF623	4	40	
	0.9	2.5	MTP5N15	5	50	
	0.8		IRF621	4	40	
	0.7		MTP7N15	7	75	
	0.6	5	IRF633	8		
	0.5	4	MTP8N15	9		
	0.4	5	IRF631			
	0.3	MTP10N15	10			
	0.25	7.5	MTP15N15	15	100	
	0.22	10	IRF643	16	125	
	0.18		IRF641	18		
	120	1.3	1.5	MTP3N12	3	50
0.9		2.5	MTP5N12	5	75	
0.7		3.5	MTP7N12	7		
0.5		4	MTP8N12	8		
0.3		5	MTP10N12	10		100
0.25		7.5	MTP15N12	15		
100	0.8	2	MTP4N10	4	50	
	0.6		IRF512	3.5	20	
			IRF510	4	50	
	0.5	3	MTP6N10	6		
		4	MTP8N10	8		75
	0.4	5	MTP8P10*	7	40	
	IRF522		10		75	
	MTP10N10					
	0.33	5	MTP12P10*	8	40	
	0.30	6	IRF520		12	75
	0.25	8	IRF532		14	
			IRF530	12		
	0.18	6	MTP12N10	20	100	
	0.15	10	MTP20N10	24	125	
	0.11	15	IRF542	27		
	0.085		IRF540	25		
	80	0.8	2	MTP25N10	4	50
		0.6	3	MTP4N08	6	75
0.5		4	MTP6N08	8		
0.4			MTP8P08*			
0.33		5	MTP10N08	10	100	
0.3		6	MTP12P08*	12		
0.18			MTP12N08			
0.15		10	MTP20N08	20		
60		0.8	2	IRF513	3.5	20
		0.6		IRF511	4	50
	0.4	2.5	MTP5N06	5		
		3.5	MTP7N06	7		

*Indicates P-Channel

Table 1 — Plastic TMOS Power MOSFETs — TO-220AB (continued)

CASE 221A-02

V _{BR(DSS)} (Volts) Min	r _{DS(on)} @ I _D (Ohms) Max (Amp)		Device	I _{D(Cont)} (Amp) Max	P _D @ T _C = 25°C (Watts) Max
60	0.4	4	IRF523	7	40
	0.3		IRF521	8	
		6	MTP12P06*	12	75
	0.28	5	MTP10N06	10	
	0.25	8	IRF533	12	
	0.2	6	MTP12N06		
	0.18	8	IRF531	14	
	0.16	7.5	MTP15N06	15	
	0.15	6	MTP3055A	12	40
	0.11	15	IRF543	24	125
	0.085		IRF541	27	
	0.08	12.5	MTP25N06	25	100
50	0.6	2.5	MTP5N05	5	50
	0.4	3.5	MTP7N05	7	
	0.3	6	MTP12P05*	12	75
	0.28	5	MTP10N05	10	
	0.16	7.5	MTP15N05	15	
	0.12	6	BUZ71A	12	40
	0.1		BUZ71		
		10	BUZ10	19	75
		7	MTP14N05A	14	40
	0.08	8	MTP16N05A	16	
		12.5	MTP25N05	25	100
		15	BUZ11A	25	75
	0.06				
	0.04		BUZ11	30	

*Indicates P-Channel

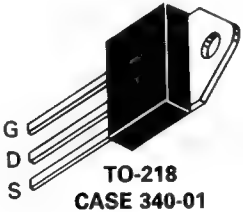
Table 2 — Plastic TMOS Power MOSFETs — TO-218AC (continued)

CASE 340-01

V _{BR(DSS)} (Volts) Min	r _{DS(on)} @ I _D (Ohms) Max (Amp)		Device	I _{D(Cont)} (Amp) Max	P _D @ T _C = 25°C (Watts) Max
450	0.8	3.5	MTH7N45	7	150
	0.4	7	MTH13N45	13	
400	0.55	4	MTH8N40	8	
	0.3	7.5	MTH15N40	15	
350	0.55	4	MTH8N35	8	
	0.3	7.5	MTH15N35	15	
200	0.7	4	MTH8P20*	8	125
	0.16	7.5	MTH15N20	15	150
	0.08	15	MTH30N20	30	
180	0.7	4	MTH8P18*	8	125
	0.16	7.5	MTH15N18	15	150
	0.08	15	MTH30N18	30	
150	0.12	10	MTH20N15	20	
	0.06	17.5	MTH35N15	35	
120	0.12	10	MTH20N12	20	
	0.06	17.5	MTH35N12	35	
100	0.07	12.5	MTH25N10	25	
	0.04	20	MTH40N10	40	
80	0.07	12.5	MTH25N08	25	
	0.04	20	MTH40N08	40	
60	0.055	17.5	MTH35N06	35	
	0.028	20	MTH40N06	40	
50	0.055	17.5	MTH35N05	35	
	0.028	20	MTH40N05	40	

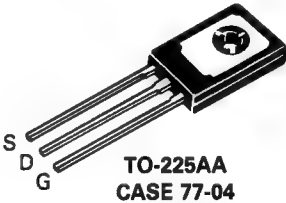
*Indicates P-Channel

Table 2 — Plastic TMOS Power MOSFETs — TO-218AC



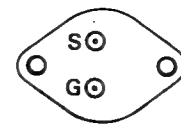
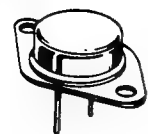
V _{BR(DSS)} (Volts) Min	r _{DS(on)} @ I _D (Ohms) Max (Amp)		Device	I _{D(Cont)} (Amp) Max	P _D @ T _C = 25°C (Watts) Max
1000	3	2.5	MTH5N100	5	150
950			MTH5N95		
900		3	MTH6N90	6	
850			MTH6N85		
600	1.2		MTH6N60		
	0.5	4	MTH8N60	8	
550	1.2	3	MTH6N55	6	
	0.5	4	MTH8N55	8	
500	0.8	3.5	MTH7N50	7	
	0.4	7	MTH13N50	13	

Table 3 — Plastic TMOS Power MOSFETs — TO-225AA



V _{BR(DSS)} (Volts) Min	r _{DS(on)} @ I _D (Ohms) Max (Amp)		Device	I _{D(Cont)} (Amp) Max	P _D @ T _C = 25°C (Watts) Max
200	1.2	2	MTA4N20	4	30
180			MTA4N18		
150	0.9	2.5	MTA5N15	5	
120			MTA5N12		
100	0.6	3	MTA6N10	6	
80			MTA6N08		
60	0.4	3.5	MTA7N06	7	
50			MTA7N05		

Table 4 — Metal TMOS Power MOSFETs — TO-204AA



TO-204 (Formerly TO-3) CASE 1-04 and CASE 1-05

V _{BR(DSS)} (Volts) Min	r _{DS(on)} @ I _D (Ohms) Max (Amp)		Device	I _{D(Cont)} (Amp) Max	P _D @ T _C = 25°C (Watts) Max	
1000	10	0.5	MTM1N100	1	75	
	7	1.5	MTM3N100	3	125	
	3	2.5	MTM5N100	5	150	
950	10	0.5	MTM1N95	1	75	
	7	1.5	MTM3N95	3	125	
	3	2.5	MTM5N95	5	150	
900	8	1	MTM2N90	2	75	
	5	2	MTM4N90	4	125	
	3	3	MTM6N90	6	150	
850	8	1	MTM2N85	2	75	
	5	2	MTM4N85	4	125	
	3	3	MTM6N85	6	150	
800	7	1.5	MTP3N80	3	75	
	2	3	BUZ84	5.3	125	
750	7	1.5	MTM3N75	3	75	
600	6	1	MTM2N60	2	150	
	2.5	1.5	MTM3N60	3		
	1.2	3	MTM6N60	6		
	0.5	4	MTM8N60	8		
550	6	1	MTM2N55	2	75	
	2.5	1.5	MTM3N55	3	150	
	1.2	3	MTM6N55	6		
	0.5	4	MTM8N55	8		
500	6	1	MTM2P50*	2	75	
	4		MTM2N50		40	
	IRF422					
	3	1.5	IRF420	2.5	75	
			MTM3N50			
	2		IRF432			
	2.5	IRF430	4.5			
		MTM4N50				
		3		2N6762		4.5
	2					
	3					
	1.1	4	IRF442	7	125	
	0.85		IRF440	8		
	0.80	3.5	MTM7N50	7	150	
	0.50		IRF452	12		
	0.40	7	IRF450	13		
			7.75	2N6770	12	
			7.5	MTM15N50	15	250
450	6	1	MTM2P45*	2	75	
	4		MTM2N45		40	
	IRF423					
	3	IRF421	2.5			
		1.5	MTM3N45	3	75	
	2	2.5	IRF433, 2N6761	4		

*Indicates P-Channel

Table 4 — Metal TMOS Power MOSFETs — TO-204AA (continued)

CASE 1-04 and CASE 1-05

V _{BR(DSS)} (Volts) Min	r _{DS(on)} @ I _D (Ohms) Max (Amp)		Device	I _{D(Cont)} (Amp) Max	P _D @ T _C = 25°C (Watts) Max	
450	1.5	2.5	IRF431	4.5	75	
		2	MTM4N45	4	125	
	1.10	4	IRF443	7		
			IRF441	8		
	0.85	3.5	MTM7N45	7	150	
	0.80		IRF453	12		
	0.50		2N6769	11		
	7	IRF451	13	250		
		0.40			MTM15N45	15
	400	3.3	1.5	MTM3N40	3	75
2.5		IRF322		2.5	40	
1.8		IRF320		3	75	
2		MTM4N40	4			
1.5		3	IRF332	4.5		
			IRF330	5.5		
1		2.5	MTM5N40	5	125	
			3.5	2N6760		5.5
0.8		5	IRF342	8		
			IRF340	10		
0.55		4	MTM8N40	8	150	
			IRF352	13		
0.40		8	IRF350	15		
			9	2N6768		14
0.30		7.5	MTM15N40	15	250	
350	3.3	1.5	MTM3N35	3	75	
	2.5		IRF323	2.5	40	
	1.8		IRF321	3	75	
	2	MTM4N35	4			
	1.5	3	IRF333/2N6759	4.5		
			IRF331	5.5		
	1	2.5	MTM5N35	5	125	
			IRF343	8		
	0.80	5	IRF341	10		
	0.55		MTM8N35	8	150	
	4	IRF353	13			
		0.4		2N6767		12
	7.75	IRF351	15			
		0.3		MTM15N35	15	250
	7.5					
250	0.45	5	MTM10N25	10	100	
200	1.2	2.5	IRF222	4	40	
	1		MTM5N20	5	75	
			MTM5P20*		40	
	0.8	IRF220				
	0.7	3.5	MTM7N20	7	75	
			MTM8P20*	8	125	
	0.6	5	IRF232	9	75	
	0.4		IRF230			
			2N6758			
	0.35	4	MTM8N20	8	100	
			MTM12N20	12		
	0.22	6	IRF242	16		125
	10					

*Indicates P-Channel

Table 4 — Metal TMOS Power MOSFETs — TO-204AA (continued)
CASE 1-04 and CASE 1-05

V _{BR} (DSS) (Volts) Min	r _{DS(on)} @ I _D (Ohms) (Amp) Max		Device	I _D (Cont) (Amp) Max	P _D @ T _C = 25°C (Watts) Max	
200	0.18	10	IRF240	18	125	
	0.16	7.5	MTM15N20	15	150	
	0.12	16	IRF252	25		
	0.085	19	IRF250	30		
	2N6766					
0.080	20	MTM40N20	40	250		
180	1	2.5	MTM5N18	5	75	
			MTM5P18*			
	0.7	3.5	MTM7N18	7		125
			4	MTM8P18*	8	
	0.40		MTM8N18		75	
	0.35	6	MTM12N18	12	100	
	0.16	7.5	MTM15N18	15	150	
	0.08	20	MTM40N18	40	250	
150	1.2	2.5	IRF223	4	40	
	0.8		IRF221	5		
	0.7	3.5	MTM7N15	7	75	
	0.6	5	2N6757	8		
			IRF233			
	0.5	4	MTM8N15	9		
	0.4	5	IRF231			
	0.3		MTM10N15		10	
	0.25	7.5	MTM15N15	15	150	
	0.22	10	IRF243	16	125	
	0.18	16	IRF241	18	150	
	0.12		MTM20N15	20		
			IRF253/2N6765	25		
	0.085		IRF251	30	250	
0.06	22.5	MTM45N15	45			
120	0.70	3.5	MTM7N12	7	75	
	0.50	4	MTM8N12	8		
	0.30	5	MTM10N12	10		
	0.25	7.5	MTM15N12	15	150	
	0.12	10	MTM20N12	20		
	0.06	22.5	MTM45N12	45	250	
	100	0.5	4	MTM8N10	8	75
0.4		MTM8P10*				
		IRF122		7	40	
0.33		5	MTM10N10	10	75	
0.30			IRF120	8	40	
		6	MTM12P10*	12	75	
0.25		8	IRF132	14		
			0.18			IRF130
						6
9		2N6756	14			
0.15		10	MTM20N10	20	100	
0.11		15	IRF142	24	125	
0.085			IRF140	27		
0.08		20	IRF152	33	150	
0.07		12.5	MTM25N10	25		

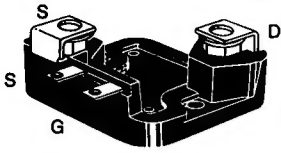
*Indicates P-Channel

Table 4 — Metal TMOS Power MOSFETs — TO-204AA (continued)
CASE 1-04 and CASE 1-05

V _{BR} (DSS) (Volts) Min	r _{DS(on)} @ I _D (Ohms) Max		(Amp)	Device	I _D (Cont) (Amp) Max	P _D @ T _C = 25°C (Watts) Max
100	0.055	20		IRF150	40	150
		24		2N6764	38	
	0.04	27.5		MTM55N10	55	250
80	0.5	4		MTM8N08	8	75
	0.4			MTM8P08*		
	0.33	5		MTM10N08	10	
	0.30	6		MTM12P08*	12	
	0.18			MTM12N08		
	0.15	10		MTM20N08	20	100
	0.07	12.5		MTM25N08	25	150
	0.04	27.5		MTM55N08	55	250
	60	0.40	4		IRF123	7
0.30				IRF121	8	
		6		MTP12P06*	12	75
0.28		5		MTM10N06	10	
0.25		8		IRF133/2N6755	12	
0.20		6		MTM12N06		
0.18		8		IRF131	14	
0.16		7.5		MTM15N06	15	
0.11		15		IRF143	24	125
0.085				IRF141	27	
0.08		12.5		MTM25N06	25	100
		20		IRF153	33	150
				2N6763	31	
			0.055	17.5		MTM35N06
	20		IRF151	40		
		0.028	30		MTM60N06	60
50	0.30	6		MTM12P05*	12	75
	0.28	5		MTM10N05	10	
	0.20	6		MTM12N05	12	
	0.16	7.5		MTM15N05	15	
	0.08	12.5		MTM25N05	25	100
	0.055	17.5		MTM35N05	35	150
	0.028	30		MTM60N05	60	250

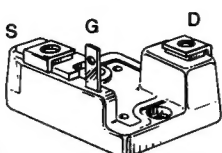
*Indicates P-Channel

Table 5 — Energy Management Series TMOS Power MOSFETs



CASE 346-01

CASE 353-01



P_D = 250 W

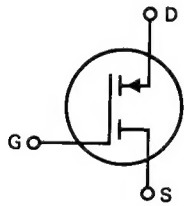
P_D = 500 W

Mounting base is connected to the drain.

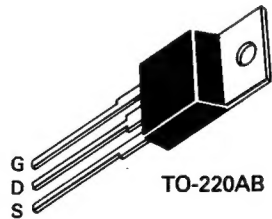


V _{DSS} (Volts)	r _{DS(on)} @ I _D		Device	I _{D(Cont)} (Amp)	P _D @ T _C = 25°C (Watts)
	(Ohms)	(Amp)			
600	0.25	10	MTE20N60	20	250
	0.13	20	MTE40N60	40	500
550	0.25	10	MTE20N55	20	250
	0.13	20	MTE40N55	40	500
500	0.20	12.5	MTE25N50	25	250
	0.10	25	MTE50N50	50	500
450	0.20	12.5	MTE25N45	25	250
	0.10	25	MTE50N45	50	500
400	0.15	15	MTE30N40	30	250
	0.08	30	MTE60N40	60	500
350	0.15	15	MTE30N35	30	250
	0.08	30	MTE60N35	60	500
200	0.048	30	MTE60N20	60	250
	0.024	60	MTE120N20	120	500
180	0.048	30	MTE60N18	60	250
	0.024	60	MTE120N18	120	500
150	0.038	32.5	MTE65N15	65	250
	0.020	65	MTE130N15	130	500
120	0.038	32.5	MTE65N12	65	250
	0.020	65	MTE130N12	130	500
100	0.028	37.5	MTE75N10	75	250
	0.012	75	MTE150N10	150	500
80	0.028	37.5	MTE75N08	75	250
	0.012	75	MTE150N08	150	500
60	0.018	50	MTE100N06	100	250
	0.009	100	MTE200N06	200	500
50	0.018	50	MTE100N05	100	250
	0.009	100	MTE200N05	200	500

Table 6 — Gain Enhanced MOSFETs (GEMFETs)



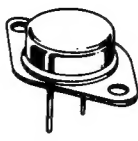
TO-204AA
(TO-3)



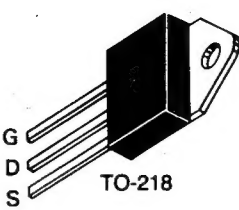
TO-220AB

V _{BR(DSS)} (Volts) Min	r _{DS(on)} @ I _D		Device	I _{D(Cont)} (Amp) Max	P _D @ T _C = 25°C (Watts) Max	Package
	(Ohms) Max	(Amp)				
500	0.27	10	MGM20N50	20	100	TO-204AA
			MGP20N50			TO-220AB
	1.6	2.5	MGM5N50	5	50	TO-204AA
			MGP5N50			TO-220AB
450	0.27	10	MGM20N45	20	100	TO-204AA
			MGP20N45			TO-220AB
	1.6	2.5	MGM5N45	5	50	TO-204AA
			MGP5N45			TO-220AB

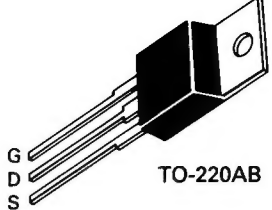
Table 7 — P-Channel TMOS Power MOSFETs



TO-204AA
(TO-3)



TO-218



TO-220AB



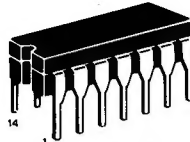
V _{BR(DSS)} (Volts) Min	r _{DS(on)} @ I _D		Device	I _{D(Cont)} (Amp) Max	P _D @ T _C = 25°C (Watts) Max	Package
	(Ohms) Max	(Amp)				
500	6	3	MTM2P50	2	75	204AA
			MTP2P50			220AB
450	6	3	MTM2P45	2	75	204AA
			MTP2P45			220AB
200	0.7	4	MTM8P20	8	125	204AA
			MTH8P20			218AC
	1	2.5	MTM5P20	5	75	204AA
			MTP5P20			220AB
180	0.7	4	MTM8P18	8	125	204AA
			MTH8P18			218AC
	1	2.5	MTM5P18	5	75	204AA
			MTP5P18			220AB
100	0.3	6	MTM12P10	12	75	204AA
			MTP12P10			220AB
	0.4	4	MTM8P10	8	75	204AA
			MTP8P10			220AB
80	0.3	6	MTM12P08	12	75	204AA
			MTP12P08			220AB
	0.4	4	MTM8P08	8	75	204AA
			MTP8P08			220AB
60	0.3	6	MTM12P06	12	75	204AA
			MTP12P06			220AB
50	0.3	6	MTM12P05	12	75	204AA
			MTP12P05			220AB

Table 8 — Military Specified TMOS Power MOSFETs


V _{BR(DSS)} (Volts) Min	r _{DS(on)} @ I _D		Device	I _{D(Cont)} (Amp)	P _D @ T _C = 25°C (Watts)	Package
	(Ohms) Max	(Amp)				
500	1.5	3	2N6762J,JTX,TXV	4.5	75	TO-204AA
	0.4	7.75	2N6770J,JTX,TXV	12	150	TO-204AA
400	1	3.5	2N6760J,JTX,TXV	5.5	75	TO-204AA
	0.3	9	2N6768J,JTX,TXV	14	150	TO-204AA
200	0.4	6	2N6758J,JTX,TXV	9	75	TO-204AA
	0.085	19	2N6766J,JTX,TXV	30	150	TO-204AE
100	0.18	9	2N6756J,JTX,TXV	14	75	TO-204AA
	0.055	24	2N6764J,JTX,TXV	38	150	TO-204AE

Note: These devices are in various stages of qualification. Consult the factory for qualification status.


Table 9 — TMOS Small-Signal MOSFETs




TO-116
(MO-001 AA)
(CASE 632-02)




TO-205AD
(TO-39)
(CASE 79-02)




TO-206AA
(TO-18)
(CASE 22-03)



TO-226AA
(TO-92)
(CASE 29-02)




TO-226AE
(CASE 29-03)




V _{(BR)DSS} (Volts) Min	r _{DS(on)} @ I _D (Ohms)		Device	I _D (Cont) (Amp) Max	P _D @ T _C = 25°C Watts Max	Package	
	Max	(Amp)					
200	14	0.2	BS107	0.25	0.6	TO-226AA (TO-92)	
	6	0.1	MPF9200	0.40	1.8	TO-206AA (TO-18)	
			MFE9200				
90	5	1	VN90AB	2	6.25	TO-205AD (TO-39)	
	4.5		VN99AB		2.5	TO-226AE	
	4		MPF6661		6.25	TO-205AD (TO-39)	
			2N6661		2.5	TO-226AE	
	2		MPF990		6.25	TO-205AD (TO-39)	
			MFE990		4	TO-116	
			MFQ990C*		0.83	TO-226AA	
60	5	0.5	BS170	0.2	2.5	TO-226AE	
		0.3	MPF910/MPF10LM	0.5	6.25	TO-205AD (TO-39)	
			MFE910		2.5	TO-226AE	
	3	1	VN67AB	2	2.5	TO-205AD (TO-39)	
			MPF6660		6.25	TO-226AE	
			2N6660		2.5	TO-205AD (TO-39)	
	1.7		MPF960		6.25	TO-205AD (TO-39)	
			MFE960		4	TO-116	
			MFQ960C*		6.25	TO-205AD (TO-39)	
			VN35AB		2.5	TO-226AB	
35	2.5	1.4	MPF930	6.25	6.25	TO-205AD (TO-39)	
	1.4		MFE930		4	TO-116	
			MFQ930C*				

*Four FETs per package.

Table 10 — Small-Signal MOSFETs — TO-205AF Type
CASE 79-03




TO-205AF Type
(TO-39 Low Profile)
(Case 79-03)



V _(DSS) (Volts)	r _{DS(on)} @ I _D		Device	I _D (Cont) (Amps)	P _D @ T _C = 25°C (Watts)
	(Ohms)	(Amps)			
500	1.5	1.5	2N6802	3.5	25
	3	1	2N6794	1.5	20
400	1	2	2N6800	3	25
	1.8	1.25	2N6792	2	20
200	0.4	3.5	2N6798	5.5	25
	0.8	2	IRFF220	3.5	20
		2.25	2N6790		
	1.2	2	IRFF222	3	
	1.5	1.5	2N6784	2.25	15
150	0.8	2	IRFF221	3.5	20
	1.2		IRFF223	3	
100	0.18	5	2N6796	8	25
		4	IRFF130	4	
	0.25	3.5	IRFF132	7	20
			2N6788	6	
	0.3	3	IRFF120	5	
	0.4	2.25	IRFF122	3.5	15
	0.6		2N6782	3	
	0.8	1.5	IRFF110	3	
			IRFF112	4	25
	0.18	4	IRFF131	7	
60	0.25	3	IRFF133	6	20
	0.3		IRFF121	5	
	0.4		IRFF123	3.5	
	0.6	1.5	IRFF111	3	15
	0.8		IRFF113		

Table 11 — Small-Signal MOSFETs — 4 Pin DIP — Case 370-01



V _{BR(DSS)} (Volts) Min	r _{DS(on)} @ I _D		Device	I _D (Cont) (Amp) Max	P _D @ T _C = 25°C (Watt) Max
	(Ohms) Max	(Amp)			
100	0.6	0.8	IRFD110	1	1
-100		-0.8	IRFD9120*	-1	
100	2.4	0.25	IRFD120	0.5	
60	0.8	0.8	IRFD113	0.8	
-60		-0.8	IRFD9123*	-0.8	
60	3.2	0.25	IRFD123	0.4	

Note: To be introduced. Consult Factory (602) 244-3061
*Indicates P-Channel.

Table 12 — TMOS Product Matrix

Id (AMP) V(DS)SS Volts	≤1	2-2.9	3-3.9	4-5	5-6	7	8	9-10	12-13	14-19	20-24	25-29	30-40	50-75	100-200
	MTM/MTP 1N100/95	MTM/MTP 2N90/85	MTM/MTP 3N100/95	MTM/MTH 5N100/95	MTM/MTH 6N90/85	MTM/MTH 7N50/45	MTM/MTH 8N60/55		IRF450 IRF451 MTH13N45 MTH13N50 IRF452 IRF453	MTM15N 50/45	MTE 20N60/55	MTE 25N50/45	MTE 40N60/55	MTE 50N50/45	
1000 950 900 850															
600 550	MTP 1N60/55	MTM/MTP 2N60/55	MTM/MTP 3N60/55		MTM/MTH MTP 6N60-55	MTM/MTH 7N50/45 IRF842 IRF843 IRF442 IRF443	MTM/MTH 8N40/35 IRF742 IRF743 IRF342 IRF343								
500 450	MTP 1N50/45	MTM/MTP 2N50/45 MTM/MTP 2P50/45 IRF420-23 IRF820-23	MTM/MTP 3N45/50	MTM/MTP 4N50/45 2N6761 2N6762 IRF430-33 IRF830-33		MTM/MTH 7N50/45 IRF842 IRF843 IRF442 IRF443	MTM/MTH 8N40/35 IRF742 IRF743 IRF342 IRF343	MTP 10N35/40 IRF740 IRF741 IRF340 IRF341	IRF450 IRF451 MTH13N45 MTH13N50 IRF452 IRF453	MTM15N 50/45	MTE 20N60/55	MTE 25N50/45	MTE 40N60/55	MTE 50N50/45	
400 350		MTP 2N40/35 IRF322 IRF323 IRF722 IRF723	MTM/MTP 3N40/45 IRF320 IRF321 IRF720 IRF721	MTM/MTP 4N35/40	MTM/MTP 5N40/35 2N6760 IRF330-33 IRF730-33		MTM/MTH 8N40/35 IRF742 IRF743 IRF342 IRF343		IRF352 IRF353	MTM/MTH 15N40/35 IRF350 IRF351			MTE 30N40/35	MTE 60N40/35	
250 180	MFE9200 MPF9200 BS170 BS107	MTP 2N20/18 MTP 2N25 IRF610-12		IRF222 IRF622 MTA/MTP 4N18/20 IRF220 IRF620	MTM/MTP 5N20/18 MTM/MTP 5P18/20	MTM/MTP 7N20/18	MTM/MTP 8N20/18 IRF232 IRF632 MTM/MTH 8P18/20	MTM/MTP 10N25 2N6758 IRF230 IRF630	MTM/MTP 12N20/18	IRF240,640 MTM 15N20/18 IRF242,642 MTH 15N20/18		IRF252	IRF250 MTM 40N20/18 MTH 30N20/18	MTE 60N20/18	MTE 120N20/18
150 120		IRF611-13	MTP 3N15/12	IRF223,623 MTA/MTP 5N12/15 IRF221 IRF621		MTM/MTP 7N15/12	IRF233 IRF633 2N6757 MTM/MTP 8N12/15	MTM/MTP 10N15/12 IRF231 IRF631 2N6757		MTM/MTP 15N15/12 IRF241,641 IRF243,643	MTM/MTH 20N15/12	IRF253	IRF251 MTM 45N15/12 MTH 35N15/20	MTE 65N15/12	MTE 130N15/12
100 80		2N6661 MPF6661 MPF990 MFE990 MFC990C	IRF512	MTP 4N10/08 IRF510	MTA/MTP 6N08/10	IRF122 IRF522	MTM/MTP 8N10/08 8P10/08 IRF120 IRF520	MTM/MTP 10N10/08	MTM/MTP 12N10/08 12P10/08 IRF132 IRF532	2N6756 IRF130 IRF530 MTH/MTH 15P08/10	MTM/MTP 20N10/08 IRF142 IRF542	MTM/MTP 25N10/08 MTH 25N10/08 IRF140 IRF540	IRF150,152 MTH40N 10/08	MTE 75N10/08 MTM 55N10/08	150N10/08
60 50	MFE910 MPF910	2N6660 MPF6660 MPF960 MPF960 MFC960	IRF513	IRF511	MTP 5N06/05 MTM/MTP 5P06/05	IRF123 IRF523 MTA/MTP 7N05/06	IRF121 IRF521	MTM/MTP 10N06/05	MTM/MTP 12N06/05 12P06/05 2N6755 IRF133 IRF533 BUZ10	MTM/MTP 15N06/05 IRF131 IRF531 MTP3055A MTP14N05A MTP16N05A	IRF143 IRF543	MTM/MTP 25N06/05 IRF141 IRF541 MTM/MTH 25P06/05 BUZ11A	MTM/MTH 35N06/05 IRF151 IRF153 MTH 40N06/05 BUZ11	MTM 60N06/05	MTE 100N06/05 MTE 200N06/05

MTM Prefix — TO-204
MTP Prefix — TO-204AB
MTH Prefix — TO-218AC
MTA Prefix — TO-225AA

MFE Prefix — TO-205AD (TO-39)
MPF Prefix — TO-226AA (TO-92)
MFC Prefix — TO-116
MTE Prefix — Case 346 or 353

IRF100 thru 400 Series — TO-204
IRF500 thru 800 Series — TO-220AB